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PROFESSIONAL PAPERS

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(FOURTH SERIES).

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EDITED BY CAPT. J. D. BLYTH, R.E. (R. OF O.),

ACTING SECRETARY, R.E. INSTITUTE.

PAPER 8.

NOTES ON THE MILITARY VALUE OF ROADS.

BY

MAJOR-GENERAL SIR J. R. L. MACDONALD,

K.C.I.E., C.B., LL.D.

(LATE ROYAL ENGINEERS).

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NOTES ON THE MILITARY VALUE OF ROADS.

1. Introductory.

This method of calculating the rate of marching on different classes of roads under various conditions is the result of considerable study and careful analysis of numerous actual cases, and should, it is hoped, assist staff officers and others to avoid serious miscalculations as to the rate of march when columns are compelled to use inferior roads or march under unfavourable conditions.

It is impossible, here, to go into the process by which the method was evolved, but the close agreement shown between rates calculated in this way with those actually observed would appear to show the soundness of the method.

A comparison of calculated and observed rates is given below.

Column A.—Rates calculated by this method, assuming that a small body of troops can march 15 miles in five hours on a good road under favourable conditions.

Column B.—Observed rates given by Von Schellendorf, who assumed that a small body could march 14 miles in five hours on a good road under favourable conditions.

In both cases any necessary halts are allowed for.

	A. Calculated.	B. Observed.
Temperature, 75° Fahr.	2·2	2·3 to 2·1
Temperature, 90° Fahr.	1·8	1·8
Sandy or greasy roads	2·7 to 1·8	2·4 to 2·1
Against strong head wind	2·2	2·0
Against very strong head wind	1·8	1·8
In rain or snow	2·7 to 2·2	2·4 to 2·1
On steeper gradients	—	2·2 to 1·8
Gradient, 1 in 15	2·2	
,, 1 in 10	1·8	
*Good Road, under Favourable Conditions.**		
Battalion	2·7	2·8
Division	2·5	2·5
Two divisions	2·2	2·3
Bad Road, under Favourable Conditions.		
Battalion	2·1	2·1
Division	1·7	1·7
Two divisions	1·5	1·4
Bad Road, under Unfavourable Conditions.		
Battalion	1·8	1·8
Division	1·4	1·6
Two divisions	1·1	1·2
Bad Road, very Unfavourable Conditions.		
Battalion	1·5	1·6
Division	1·1	1·3
Two divisions	·7	·9

* As Von Schellendorf's rates are based on the average of a number of observations on different roads, the calculation has been made for a road, which, while it may fairly be classed as good, is not in all respects equal to a perfect marching road, on which the rate would be 3 miles an hour for a battalion.

In addition to the above, numerous other cases have been compared, with the result that the calculated rates very rarely differ from those observed by as much as 10 per cent.

2. GENERAL METHOD FOR CALCULATING RATES OF MARCHING.

It is frequently stated in military textbooks that movements of large bodies of troops must be confined to main roads, as it is so difficult to estimate the rate of marching on inferior roads.

The following method of calculating the rate of march of columns on various classes of roads is relatively simple, gives results which agree closely with facts in a large number of actual cases to which it has been applied, and, at the worst, should prevent serious miscalculation.

It has been found that troops and transport can march at their normal rates, including short halts, on a well-metalled road so long as the gradient does not exceed 1 in 25. The rate of march on any inferior road may be expressed as a percentage of the above, and this percentage, shown as a decimal, is hereafter called the "Road Factor," or simply "F."

The rate of march which governs that of any large body depends on the rate (r) of its rear, when allowance must be made, not only for any retardation of the head of the column due to bad gradients or inferior surface, but also for the delay due to keeping the column reasonably closed up. This additional delay depends on the length of marching column, and on the width of road relative to the formation in column of route, this last consideration exercising a very marked effect on narrow roads.

Thus in finding the rate of the rear of any column we must proceed as follows :—

First.—Find "F," the factor for the given road (Table I. or II.).

Second.—Find "K," the coefficient for the width of road relative to the formation (Table IV.).

Third.—Look out in the table the rate of the rear of the column corresponding to the value, given in the first column of the table, of K×L* or K×M*, whichever be less (Table V.).

3. TO DETERMINE THE ROAD FACTOR.

The road factor, for gradient and surface, may be obtained from the following table by inspection. It must be reduced if necessary, for unfavourable, or very unfavourable conditions.

* The reason why only the smaller of these values is taken is that only the actual length of marching column causes delay. Thus as long as the column is shorter than the march the delay increases with the length of column, until the length of column reaches, or exceeds, the length of march, when the delay becomes constant, and does not further vary.

TABLE I.

TABLE OF ROAD FACTORS.

GRADIENT.	SURFACE. Good.	Indifferent.	Bad.
TROOPS WITH FIRST-LINE TRANSPORT, OR PACK ANIMALS OF SECOND-LINE TRANSPORT (deduced from practice).			
Gradient, 1 in 25, or less	1	·9	·8
,, 1 in 20	·9	·8	·7
,, 1 in 15	·8	·7	·6
,, 1 in 10	·7	·6	·5
,, 1 in 8	·6	·5	·4
VEHICLES OF SECOND-LINE TRANSPORT (deduced from practice).			
Metalled Roads.			
Gradient, 1 in 25, or less	1	·85	·7
,, 1 in 20	·9	·75	·6
,, 1 in 15	·8	·65	·5
,, 1 in 10	·7	·55	·4
Unmetalled Roads.			
Gradient, 1 in 25, or less	1	·8	·6
,, 1 in 20	·9	·7	·5
,, 1 in 15	·8	·6	·4
,, 1 in 10	·7	·5	·3
MECHANICAL TRANSPORT (estimated).			
Gradient, 1 in 25, or less	1	·7	·5 to ·4
,, 1 in 20	·85	·65	·45 to ·35
,, 1 in 15	·7	·6	·4 to ·3
,, 1 in 10	·55	·45	·3 to ·25

For unfavourable conditions deduct ·1.
For very unfavourable conditions deduct ·2.

As a guide to the effect of *Surfaces* the following may be given :—

Indifferent.—Indifferently metalled ; very dusty ; rather cut up ; greasy ; muddy ; rough ; stony.

Bad.—Badly metalled ; 4 to 6 in. of mud ; deep sand ; loose shingle ; very slippery ; 9 in. of snow ; very soft ; very rough ; very stony.

As a guide to the classification of *Conditions* the following may be given :—

Unfavourable.—Rainy ; stormy ; hot and sultry ; after a forced march ; after a bad bivouac ; after insufficient food or rest ; men and animals poorly trained ; men and animals in poor condition.

Very Unfavourable.—A combination of unfavourable conditions ; marching against a strong head wind ; making a third forced march in succession ; temperature, 75° Fahr. (If the temperature is 90° deduct ·3).

EXAMPLE I.—The road has an average gradient of 1 in 15, an indifferent surface, and the conditions are unfavourable. What is the road factor ?

From the road-factor table for a gradient of 1 in 15, F=·7 for an indifferent surface ; from this we must deduct ·1 for the unfavourable conditions.

The required road factor is accordingly ·6 for troops.* If infantry can march 3 miles an hour on a good road the head of the column might safely be expected to do 3×F, or 3×·6, *i.e.* 1·8 miles an hour on the given road under the given conditions.

4. AVERAGE RATE OF ROAD FACTOR.

When the march is over sections of road differing widely in character it may be necessary to find a mean value for F.

With a little practice, this can be estimated very closely, but the method of calculating the mean is as follows :—

Divide each length of road by its factor, and take the sum of the quantities so obtained ; then the mean value of the road factor for the march as a whole is the total length of march divided by the above sum.

EXAMPLE 2.—The march is 12 miles ; for 4 miles the road factor is 1, and for the remaining 8 miles it is ·7 ; what is the mean value ?

$$\frac{4}{1}=4.$$

$$\frac{8}{\cdot 7}=\frac{11\cdot 4}{15\cdot 4}.$$

The required mean value of F is—

$$\frac{12}{15\cdot 4}, \text{ or } \cdot 78, \text{ say } \cdot 8.$$

5. APPROXIMATE DETERMINATION OF ROAD FACTOR.

It may frequently happen in practice that sufficient information may not be forthcoming to determine the actual value of the road factor, although the general nature and condition of the road are sufficiently known. Or though the data are available, a rough approximation may be deemed sufficient for hasty calculation.

To meet such cases Table II. is given, from which an approximate value of the road factor may be obtained by inspection for various classes of roads and surfaces.

In the last columns of this table are shown also the approximate values of K, which is a coefficient necessary for the determination of the rate of the rear of columns, and which depends on the width of road relative to the formation employed by the column.

* For second-line transport, the deduction for surface would be ·15 instead of ·1, and F′ would be ·55. So the leading vehicle instead of marching at 2·75 miles an hour, could only accomplish 2·75×·55, or 1·51 miles an hour (see p. 10, Table III.).

II.—APPROXIMATE VALUES OF F AND K.

Nature of Road.	Value of F. Troops, 1st Line Transport and Pack Animals of 2nd Line Transport.	Value of F. Vehicles of 2nd Line Transport.	Value of F. Motor Lorries.	Value of K.	
First Class (in Plains or Hills).					
Surface, good	1·0	1·0	1·0	K = 1	
,, indifferent ..	·9	·85	·7		
,, bad	·8	·7	·5		
Second Class (in Plains).				Troops ..	K = 1·3
Surface, good	1·0	1·0	1·0	Horsed vehicles	K = 1
,, indifferent ..	·9	·85	·7	Motor lorries	K = 1
,, bad	·8	·7	·5	Pack mules (2 abreast) ..	K = 2
Second Class (in Hills).				Pack mules (single file) ..	K = 1
Surface, good	·9	·85	·85	Camels ..	K = 1
,, indifferent ..	·8	·75	·65	Bullock carts	K = 1
,, bad	·7	·6	·45		
Third Class (in Plains).				Troops ..	K = 2
Surface, good	·9	·85	·85	Horsed vehicles	K = 2
,, indifferent ..	·8	·75	·65	Motor lorries	K = 2·4
,, bad	·7	·6	·45	Pack mules (2 abreast) ..	K = 3
Third Class (in Hills).				Pack mules (single file) ..	K = 1
Surface, good	·8	·75	·7	Camels ..	K = 2·3
,, indifferent ..	·7	·65	·6	Bullock carts	K = 2
,, bad	·6	·5	·4		
Easy Mule Road (in Hills).					
Surface, good	·8	—	—	Troops in file	K = 1
,, indifferent ..	·7	—	—	Motor lorries	K = 2·8
,, bad	·6	—	—	Pack mules (single file) ..	K = 1·6
				Camels ..	K = 2·8
Steep Mule Road (in Hills).					
Surface, good	·7	—	—	Troops in file	K = 1·7
,, indifferent ..	·6	—	—	Pack mules (single file) ..	K = 2·3
,, bad	·5	—	—		

A deduction of ·1 or ·2 must be made from the above values of F, if the conditions are unfavourable or very unfavourable respectively.

6. GENERAL CONSIDERATIONS.

Both men and animals are trained or accustomed to march at certain fairly constant rates, which can only be increased or decreased, at the expense of extra fatigue. To gain some definite object it may be justifiable to force the pace and resort to rapid marching, but as a rule such a procedure is not considered to increase the length of march otherwise possible, but only to reduce the time in which it is accomplished. When the circumstances as regards gradient, surface or conditions are unfavourable the work required to march a specified distance is increased, and it is established that under such circumstances the rate of marching is naturally reduced. These circumstances are dealt with by means of the road factor, F.

Again it is found that short periodical halts are necessary, and

these are allowed for in fixing the normal rates of marching, R, on a standard road.

Both the above considerations affect the rate attainable by the head of a column of troops.

The rate attainable by the rear of the same column is further affected by the delay inherent in the length of marching column, and by a certain, and on a narrow road a large, amount of interference due to the width of road relative to that required by the formation adopted by the column of route. The rate of the rear is thus less than that attainable by the head of the column, which would consequently march away from the rear, unless additional halts are given; these halts are included in the rate r for the rear of the column.

7. RATE OF THE HEAD OF A COLUMN.

There is a fairly uniform concensus of opinion as to the rates of marching under favourable circumstances.

The Table III. gives those to be allowed on a standard road, a first-class road with a good surface and under favourable conditions, that is when F=1.

For lower values of F the average rate attainable by the head of the column is RF, R being obtained from Table III., and F determined as in the last chapter.

This rate RF includes the usual short periodical halts.

It will be noted that some of the values of R as given in the table are greater than those usually given in textbooks; this is to be expected, as it must be remembered that the latter give average rates in an attempt to fix one which may be used for various classes of roads, while those given in the table are more of the nature of a maximum on a first-class standard road where the road factor is unity.

III.—CERTAIN DATA AFFECTING THE RATE OF MARCH.

Troops and Transport.	R in miles per hour, viz., the Rate of the Head of a Column on a Standard Road when the Road Factor is Unity.	Minimum Width of Road Required.	Width of Road to avoid Interference (in which case K=1).
Troops with First-Line Transport.			
Infantry in fours	3	12	24
,, file	3	6	12
Second-Line Transport.			
Horsed vehicles	2·75	8	16
Motor lorries	10	9	18
Pack mules (single file)	3	6	12
Camels (single file)	2·25	9	18
Bullock carts	2	8	16

NOTE.—Some of these values of R are greater than those usually given in textbooks, but it will be remembered that the latter give average rates to cover various classes of roads, while those here given are on a first-class standard road where the road factor is unity.

8. COEFFICIENT K FOR WIDTH OF ROAD.

The width of road relative to that required by the formation adopted by the troops exercises a great effect on the rate of the rear of the column. The coefficient can be obtained from the following table, IV. :—

TABLE IV.

Average Width of Road in Feet.	24.	22.	20.	18.	16.	14.	12.	10.	8.	6.
	Value of Coefficient K.									
Troops with First-Line Transport.										
Infantry in fours	1·0	1·1	1·3	1·5	1·6	1·8	2·0			
„ file	1·0	1·0	1·0	1·0	1·0	1·0	1·0	1·3	1·7	2·0
Second-Line Transport (in Single File).										
Horsed vehicles	1·0	1·0	1·0	1·0	1·0	1·6	2·0	2·5	3·0	
Motor lorries	1·0	1·0	1·0	1·3	1·7	2·0	2·4	2·8		
Pack mules	1·0	1·0	1·0	1·0	1·0	1·0	1·0	1·6	2·3	3·0
Camels	1·0	1·0	1·0	1·0	1·4	1·8	2·3	2·8		
Bullock carts	1·0	1·0	1·0	1·0	1·0	1·5	2·0	2·5	3·0	

The narrowest portion of the road determines the formation to be adopted, while the coefficient, K, depends on the average width of the road. In estimating this average discard any portion of the width which is in excess of that shown in the last column of Table III., viz. of twice that required by the formation, the vehicle, or pack animal.

For instance, when the infantry are in fours, a section of road 30 ft. wide would be reckoned 24 ft. wide, as the extra 6 ft. exercises no appreciable effect on the rate of march.

When on broad roads vehicles or pack animals are marching two or more abreast, divide the width of road by the number abreast, and take the value of K corresponding to this reduced width, as if the vehicles or pack animals were in single file.

9. RATE OF THE REAR OF A COLUMN.

The rate r for the rear of a column not only allows for any retardation of the head of the column, but also for the delay due to the length of marching column and to interference arising from the width of road relative to the formation, and thus includes not only the short periodical halts but also those necessary for closing up.

It may be desirable to make clear what is meant by the length of marching column, and this can best be done by means of an example. If we have a 9-mile column of troops on a standard road marching 20 miles, then the whole column is on the move at the same time and the delay is due to the 9 miles of column ; the rate of march of its rear would be $r=2·7$ miles an hour. If however the march was only 5 miles, the greatest length of column on the move at

one time cannot exceed 5 miles, and the rate would be 2·83 miles an hour.

The rate of march for the rear of a column can be obtained by inspection from Table V. the necessary data being :—

F the road factor, obtained from Tables I. or II.
K the coefficient for width of road from Table IV.
L the length of column in miles.
M the length of march in miles.

The value of *r* is obtained under F in the Table V. and opposite KL or KM, whichever gives the smaller product.

V.—RATE OF MARCHING (*r*) OF REAR OF COLUMN

(including short periodical halts and halts for closing up).

If L=length of column in miles. M=length of march in miles. K=coefficient for width of road. KL or KM (whichever is less).	Troops with 1st-Line Transport.	Horsed Vehicles of 2nd-Line Transport.	Motor Lorries.	Troops with 1st-Line Transport.	Horsed Vehicles of 2nd-Line Transport.	Motor Lorries.	Troops with 1st-Line Transport.	Horsed Vehicles of 2nd-Line Transport.	Motor Lorries.	Troops with 1st-Line Transport.	Horsed Vehicles of 2nd-Line Transport.	Motor Lorries.
	F=1			F=·9			F=·8			F=·7		
3	2·9	2·6	9·7	2·6	2·4	8·7	2·3	2·1	7·7	2·0	1·7	6·7
6	2·8	2·5	9·4	2·5	2·2	8·4	2·2	1·9	7·3	1·8	1·6	6·3
9	2·7	2·3	9·1	2·4	2·1	8·1	2·1	1·8	7·0	1·7	1·4	6·0
12	2·6	2·2	8·8	2·3	2·0	7·8	1·9	1·6	6·7	1·6	1·2	5·6
15	2·5	2·1	8·5	2·2	1·8	7·5	1·8	1·5	6·3	1·5	1·1	5·3
18	2·5	2·0	8·2	2·1	1·7	7·1	1·7	1·3	6·0	1·3	·9	4·9
21	2·4	1·9	7·9	2·0	1·6	6·8	1·6	1·1	5·7	1·2	·7	4·6
24	2·3	1·7	7·6	1·9	1·4	6·5	1·5	1·0	5·3	1·1	·6	4·2
27	2·2	1·6	7·3	1·8	1·3	6·2	1·4	·9	5·0	1·0	·4	3·9
30	2·1	1·5	7·0	1·7	1·2	5·9	1·3	·7	4·7	·8	—	3·5
36	1·9	1·4	6·4	1·5	·9	5·2	1·0	·5	4·0	·6	—	3·2
42	1·7	1·3	5·8	1·3	·6	4·6	·8	—	3·4	·3	—	2·8
45	1·6	1·1	5·5	1·2	·4	4·3	—	—	—	—	—	—
48	1·5	1·0	5·2	1·1	—	4·0	—	—	—	—	—	—
54	1·4	·9	4·6	·9	—	3·3	—	—	—	—	—	—
	F=·6			F=·5			F=·4			F=·3		
3	1·7	1·4	5·7	1·3	1·2	4·7	1·0	·9	3·7	·7	·6	2·6
6	1·5	1·2	5·3	1·2	1·0	4·3	·8	·7	3·3	·5	·4	2·1
9	1·3	1·1	4·9	1·0	·8	3·9	·6	·5	3·0	·3	·2	1·7
12	1·2	·9	4·5	·9	·6	3·5	·4	·3	2·5	—	—	1·3
15	1·1	·8	4·2	·7	·4	3·2	—	—	2·1	—	—	—
18	1·0	·6	3·8	·6	—	2·8	—	—	1·6	—	—	—
21	·8	·3	3·5	·4	—	2·4	—	—	—	—	—	—
24	·7	—	3·1	—	—	2·0	—	—	—	—	—	—
27	·6	—	2·6	—	—	—	—	—	—	—	—	—

EXAMPLE.—If L=10 miles, K=1·2, and F=·9, then the rear of the 10-mile column of troops could march at 2·3 miles an hour, which corresponds to a value of KL=12.

V.—RATE OF MARCHING (r) OF REAR OF COLUMN
(including short periodical halts and halts for closing up).

If L=length of column in miles. M=length of march in miles. K=coefficient for width of road. KL or KM (whichever is less).	Pack Mules.	Camels.	Bullock Carts.	Pack Mules.	Camels.	Bullock Carts.	Pack Mules.	Camels.	Bullock Carts.	Pack Mules.	Camels.	Bullock Carts.
	F=1			F=·9			F=·8			F=·7		
3	2·9	2·1	1·9	2·6	1·9	1·7	2·3	1·6	1·5	2·0	1·4	1·2
6	2·8	2·0	1·8	2·4	1·7	1·5	2·1	1·4	1·3	1·8	1·2	1·1
9	2·6	1·8	1·6	2·3	1·5	1·4	2·0	1·3	1·2	1·6	1·0	·9
12	2·5	1·7	1·5	2·2	1·4	1·3	1·8	1·1	1·0	1·5	·9	·8
15	2·4	1·5	1·4	2·0	1·2	1·1	1·7	·9	·9	1·3	·7	·6
18	2·3	1·4	1·3	1·9	1·0	1·0	1·5	·8	·7	1·2	·5	·5
21	2·2	1·2	1·2	1·8	·9	·9	1·3	·6	·5	1·0	·3	·3
24	2·0	1·1	1·0	1·6	·7	·7	1·2	·4	·4	·9	—	·2
27	1·9	·9	·9	1·5	·5	·6	1·1	—	—	·7	—	—
30	1·8	·8	·8	1·4	·4	·5	1·0	—	—	·5	—	—
30	1·6	·5	·7	1·1	—	·2	·7	—	—	·2	—	—
42	1·3	·2	·6	·9	—	—	·4	—	—	—	—	—
45	1·2	—	·4	·7	—	—	—	—	—	—	—	—
48	1·1	—	·3	·6	—	—	—	—	—	—	—	—
54	·8	—	·2	·3	—	—	—	—	—	—	—	—
	F=·6			F=·5			F=·4			F=·3		
3	1·6	1·2	1·0	1·3	1·0	·9	1·0	·7	·6	·7	·5	·4
6	1·4	1·0	·8	1·1	·8	·6	·8	·4	·4	·5	·2	·2
9	1·3	·8	·7	1·0	·6	·5	·6	·2	·2	·3	—	—
12	1·1	·6	·5	·8	·4	·3	·4	—	—	—	—	—
15	1·0	·4	·4	·6	·2	—	·2	—	—	—	—	—
18	·8	·2	·2	·4	—	—	—	—	—	—	—	—
21	·6	—	—	·2	—	—	—	—	—	—	—	—
24	·5	—	—	—	—	—	—	—	—	—	—	—

EXAMPLE.—If L=5 miles, K=1·2, and F=·8, then the rear of a 5-mile column of camels could march at 1·4 miles an hour, as KL=5×1·2=6.

10. RATE OF REAR IN HOMOGENEOUS COLUMNS.

Homogeneous columns are those composed entirely of troops with their first line transport, or wholly of second line transport. In such cases the value of r can be found directly from Table V., by inspection.

EXAMPLE 3.—The road has a factor of ·9, and a width of 20 ft. The column consists of 10 miles of troops. What would be the rate of the rear of the column, the march being 16 miles?

Here F=·9; KL=1·3×10=13; so r=2·27 miles an hour.

EXAMPLE 4.—The road is as above. What would be the rate of a column of horsed vehicles, occupying 5 miles in column of route?

Here F′=·9; K′L′=1×5=5; so r'=2·26 miles an hour.

EXAMPLE 5.—The road is as above. What would be the rate of the rear of a 10-mile column of troops, the march being 5 miles only?

As M is less than L, we use MK in finding r.

Here F=·9; KM=1·3×5=6·5; so r=2·49 miles an hour.

11. RATE OF REAR IN MIXED COLUMNS.

Mixed columns here mean those composed of troops (accompanied as usual by their first-line transport), and second-line transport.

In such cases the value of r' for the rear of the second-line transport may have to be corrected, should the rate r of the rear of the troops fall below R'F' that of the head of the second-line transport.

EXAMPLE 6.—The road has a factor of ·9, and a width of 20 ft. The column consists of 10 miles of troops, L, followed by 5 miles of second-line transport, L', including troops which from their position in the column of route may have to conform to the transport rate of marching. What would be the rate of the rear of the column ?

For troops. RF$=3\times\cdot9=2\cdot7$ miles an hour.

$r=2\cdot27$ miles an hour (KL being $=1\cdot3\times10=13$).

For transport. R'F'$=2\cdot75\times\cdot9=2\cdot47$ miles an hour.

$r'=2\cdot26$ miles an hour (K'L' being$=1\times5=5$).

Now we see that the rate of the rear of the troops, 2·27 miles an hour, is less than that attainable by the head of the transport, 2·47 miles an hour, and that the transport is delayed to this extent.

So the rate of the rear column is $2\cdot26-\cdot2=2\cdot06$ miles an hour.

12. HALTS FOR CLOSING UP.

These are included in the rate r for the rear of the column as obtained from Table V., but it may often be desirable to estimate the time the head of the column should halt to enable the rear to close up to its normal distance.

Take the case of a 10-mile column of troops on a road which has a factor of ·9 and a width of 20 ft. We saw in Example 3 that the rate of the rear would be 2·27 miles an hour, while the rate of the head would be 2·7 miles an hour, the general rate of the column being calculated at the former rate. If the head of the column marched 12 miles, the time taken would be $\frac{12}{2\cdot7}$ or 4·44 hours.

At the rate of the rear of the column the time would be $\frac{12}{2\cdot27}$, or 5·28 hours.

Thus the halt for closing up would be $5\cdot28-4\cdot44$, or ·84 of an hour, say 50 minutes.

13. USE OF RECIPROCALS.

In calculations such as the above it is troublesome to have to divide by figures running to two places of decimals, and the computation is much simplified by multiplying by the reciprocal of the number, given in Table VI.

For instance the reciprocal of 2·7 is ·37, and $\frac{12}{2\cdot7}=12\times\cdot37=4\cdot44$, while the reciprocal of 2·27 being ·44, $\frac{12}{2\cdot27}=12\times\cdot44=5\cdot28$.

VI.—TABLE OF RECIPROCALS.

Rate.	Reciprocal.	Rate.	Reciprocal.	Rate.	Reciprocal.	Rate	Reciprocal.	Rate	Reciprocal.
·11	9·091	·77	1·299	1·43	·699	2·09	·478	2·75	·364
·12	8·333	·78	1·282	1·44	·694	2·10	·476	2·76	·362
·13	7·692	·79	1·266	1·45	·690	2·11	·474	2·77	·361
·14	7·143	·80	1·250	1·46	·685	2·12	·472	2·78	·360
·15	6·667	·81	1·235	1·47	·680	2·13	·469	2·79	·358
·16	6·250	·82	1·220	1·48	·676	2·14	·467	2·80	·357
·17	5·882	·83	1·205	1·49	·671	2·15	·465	2·81	·356
·18	5·556	·84	1·190	1·50	·667	2·16	·463	2·82	·355
·19	5·263	·85	1·176	1·51	·662	2·17	·461	2·83	·353
·20	5·000	·86	1·163	1·52	·658	2·18	·459	2·84	·352
·21	4·762	·87	1·149	1·53	·654	2·19	·457	2·85	·351
·22	4·545	·88	1·136	1·54	·649	2·20	·455	2·86	·350
·23	4·348	·89	1·124	1·55	·645	2·21	·452	2·87	·348
·24	4·167	·90	1·111	1·56	·641	2·22	·450	2·88	·347
·25	4·000	·91	1·099	1·57	·637	2·23	·448	2·89	·346
·26	3·846	·92	1·087	1·58	·633	2·24	·446	2·90	·345
·27	3·704	·93	1·075	1·59	·629	2·25	·444	2·91	·344
·28	3·571	·94	1·064	1·60	·625	2·26	·442	2·92	·342
·29	3·448	·95	1·053	1·61	·621	2·27	·441	2·93	·341
·30	3·333	·96	1·042	1·62	·617	2·28	·439	2·94	·340
·31	3·226	·97	1·031	1·63	·614	2·29	·437	2·95	·339
·32	3·125	·98	1·020	1·64	·610	2·30	·435	2·96	·338
·33	3·030	·99	1·010	1·65	·606	2·31	·433	2·97	·337
·34	2·941	1·00	1·000	1·66	·602	2·32	·431	2·98	·336
·35	2·857	1·01	·990	1·67	·599	2·33	·429	2·99	·334
·36	2·778	1·02	·980	1·68	·595	2·34	·427	3·00	·333
·37	2·703	1·03	·971	1·69	·592	2·35	·426	3·01	·332
·38	2·631	1·04	·961	1·70	·588	2·36	·424	3·02	·331
·39	2·564	1·05	·952	1·71	·585	2·37	·422	3·03	·330
·40	2·500	1·06	·943	1·72	·581	2·38	·420	3·04	·329
·41	2·439	1·07	·935	1·73	·578	2·39	·418	3·05	·328
·42	2·381	1·08	·926	1·74	·575	2·40	·417	3·06	·327
·43	2·326	1·09	·917	1·75	·571	2·41	·415	3·07	·326
·44	2·273	1·10	·909	1·76	·568	2·42	·413	3·08	·325
·45	2·222	1·11	·901	1·77	·565	2·43	·412	3·09	·324
·46	2·174	1·12	·893	1·78	·562	2·44	·410	3·10	·323
·47	2·128	1·13	·885	1·79	·559	2·45	·408	3·11	·322
·48	2·083	1·14	·877	1·80	·556	2·46	·407	3·12	·321
·49	2·041	1·15	·870	1·81	·552	2·47	·405	3·13	·319
·50	2·000	1·16	·862	1·82	·549	2·48	·403	3·14	·318
·51	1·961	1·17	·855	1·83	·546	2·49	·402	3·15	·317
·52	1·923	1·18	·847	1·84	·543	2·50	·400	3·16	·316
·53	1·887	1·19	·840	1·85	·541	2·51	·398	3·17	·315
·54	1·852	1·20	·833	1·86	·538	2·52	·397	3·18	·314
·55	1·818	1·21	·826	1·87	·535	2·53	·395	3·19	·313
·56	1·786	1·22	·820	1·88	·532	2·54	·394	3·20	·313
·57	1·754	1·23	·813	1·89	·529	2·55	·392	3·21	·312
·58	1·724	1·24	·806	1·90	·526	2·56	·391	3·22	·311
·59	1·695	1·25	·800	1·91	·524	2·57	·389	3·23	·310
·60	1·667	1·26	·794	1·92	·521	2·58	·388	3·24	·309
·61	1·639	1·27	·787	1·93	·518	2·59	·386	3·25	·308
·62	1·613	1·28	·781	1·94	·515	2·60	·385	3·26	·307
·63	1·587	1·29	·775	1·95	·513	2·61	·383	3·27	·306
·64	1·563	1·30	·769	1·96	·510	2·62	·382	3·28	·305
·65	1·538	1·31	·763	1·97	·508	2·63	·380	3·29	·304
·66	1·515	1·32	·758	1·98	·505	2·64	·379	3·30	·303
·67	1·493	1·33	·752	1·99	·503	2·65	·377	3·31	·302
·68	1·471	1·34	·746	2·00	·500	2·66	·376	3·32	·301
·69	1·449	1·35	·741	2·01	·498	2·67	·375	3·33	·300
·70	1·429	1·36	·735	2·02	·495	2·68	·373	3·34	·299
·71	1·408	1·37	·730	2·03	·493	2·69	·372	3·35	·299
·72	1·389	1·38	·725	2·04	·490	2·70	·370	3·39	·295
·73	1·370	1·39	·719	2·05	·488	2·71	·369	3·37	·297
·74	1·351	1·40	·714	2·06	·485	2·72	·368	3·38	·296
·75	1·333	1·41	·709	2·07	·483	2·73	·366	3·39	·295
·76	1·316	1·42	·704	2·08	·481	2·74	·365	3·40	·294

14. MARCHING ACROSS COUNTRY.

This is frequently assumed to be two-thirds of that on a road.

An approximate road factor may be found for a cross-country march from the table of road factors; from this a deduction of ·1 should be made as moving across country is always more fatiguing than on a road; a further deduction of ·1 may be made when the country traversed is enclosed.

Though the rate of the head of a column is thus considerably less than on a road, the rate of the rear is usually relatively higher, as the troops are not confined to a road so that K=1, and the movement can generally be made in a number of short columns instead of in one of considerable length.

15. NIGHT MARCHING.

The following may be considered the rates by night :—

On bright moonlight nights	..	$\frac{5}{6}$ of the rate by day.
On clear starlight nights	..	$\frac{2}{3}$ of the rate by day.
On dark cloudy nights ..	..	$\frac{1}{2}$ the rate by day.

When part of a march is by day and part by night it is simplest to calculate as for daylight only, and then to modify the time required according to the above proportions.

When the time available is known and the length of march is to be found, consider each hour by night as equivalent to the above proportion by day according to the nature of the night. For example if the time available is 5 hours by day and $4\frac{1}{2}$ hours by bright starlight, the equivalent time is $5+4\frac{1}{2}\times\frac{2}{3}=8$ hours, and the possible march is that which could be accomplished in 8 hours of daylight.

When the march is known and the time required is to be found, calculate the latter as by daylight, and increase that portion which must be marched by night in the inverse proportion.

For instance it is calculated that a given march can be made in 8 hours by day, but there are only 5 hours of daylight available and the remainder of the march must be completed by bright starlight. The actual time required would be $5+3\times\frac{3}{2}=9\frac{1}{2}$ hours.

16. SPECIAL RATES OF MARCHING.

The values of r for the rear of columns as given in Table V. are based on the standard rates given in the second column of Table III.

But the values obtained from Table V. may be adapted to any special rates of marching by a proportional increase or decrease.

For instance supposing that troops are specially trained so that a small body can march 4 miles an hour on a standard first-class

road under favourable conditions, instead of the 3 miles an hour given in Table III., then the value of r obtained from Table V. may be multiplied by $\frac{4}{3}$. If on the contrary a small body could only accomplish $2\frac{1}{2}$ miles on a standard road, the value of r as obtained from Table V. would be multiplied by $\frac{2\frac{1}{2}}{3}$.

17. General Consideration of Length of March.

For an individual, or small body of troops, the distance which can be marched in a given time is a product of the time in hours multiplied by the rate in miles per hour.

This simple relation does not, however, hold good when the march of columns is dealt with. Complications are introduced by a number of different causes, which must be properly understood if the best results are to be obtained. These complications will be dealt with separately and will be only touched on here.

In the case of the individual, or small body of troops, there is no appreciable length of column to consider, but with columns of any length the degree of concentration necessary at the end of the march reduces the length of march by a varying amount, which, when the column is concentrated at night in a single camp or bivouac, is equal to the length of the column when on the march. For instance, if a 10-mile column of troops on a given road can march 2·27 miles an hour, in 10 hours the head of the column could cover 22·7 miles, but if the whole column is to be concentrated at night, it is obvious that its head must halt 10 miles short of the point it could otherwise attain, or in other words at the point which could be reached by its rear, so that the march is reduced to 12·7 miles.

If the column bivouacked in column of route it could theoretically march 22·7 miles, but in ordinary cases this is impracticable.

It is however frequently, indeed generally, possible to camp or bivouac in a number of echelons instead of concentrating at night, and in this way a march between 12·7 and 22·7 miles becomes possible, the gain over the former limit being hereafter called C.

A further complication arises when the column is dependent on its second line transport for necessary food, etc., as in such cases the troops must halt at the point which their second-line transport can reach in the given time, and the march may be much reduced in consequence. Where the country traversed is populous and fertile the troops may be independent of their second line transport for a time and may live on the country, in which case longer marches may be made.

The above remarks will elucidate the general formula for the length of march, but the latter may be further reduced by causes which will be considered later, such as rest halts necessary on long

marches, the limitations due to the limits of individual effort and the provision of adequate repose, and delay caused by obstacles *en route*.

18. GENERAL FORMULÆ FOR LENGTH OF MARCH.

The following symbols will be adopted :—

L=the length of troops and first-line transport in miles.
L′=the length of second-line transport in miles, including troops and first-line transport which from their position in the column of route have to conform to the rate of second-line transport.
r=the rate of the rear of L in miles per hour.
r'=the rate of the rear of L′ in miles per hour.
M=the length of march in miles.
C=the gain from the use of echeloned camps (with concentrated camps C=O).
T=the number of hours available.
D=the delay due to obstacles (dealt with later).

Separate formulæ are necessary for homogeneous and mixed columns.

1. For homogeneous columns, which consist entirely of troops, or entirely of second-line transport.

$$T \times r - L + C = M \text{ for troops.}$$

$$T \times r' - L' + C = M \text{ for second-line transport.}$$

2. For mixed columns (consisting partly of troops and partly of second-line transport).

$$\left(T - \frac{L}{r}\right) r' - L' + C = M.$$

If a second and slower moving class of second-line transport of length L″ be included in the column, and r'' is the rate of the rear of L″, then Formula 2 would take the form

$$\left(T - \frac{L}{r} - \frac{L'}{r'}\right) r'' - L'' + C = M.$$

The fraction $\frac{L}{r}$ is an expression of the time taken by the troops in moving into column of route on the road, and can be obtained by inspection from Table VII. It is obvious the head of the second-line transport cannot begin to march until the troops ahead of it have left camp.

VII.—TIME TAKEN TO TRAVERSE A GIVEN DISTANCE AT A GIVEN RATE, USED FOR OBTAINING THE VALUE OF $\frac{L}{r}$.

Rate r.	Distance (L). 1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
3	·33	·66	1·00	1·33	1·66	2·00	2·33	2·66	3·00	3·33
2·9	·35	·69	1·04	1·38	1·73	2·08	2·43	2·77	3·10	3·44
2·8	·36	·71	1·07	1·43	1·79	2·14	2·50	2·86	3·20	3·57
2·7	·37	·74	1·11	1·48	1·85	2·22	2·59	2·90	3·33	3·70
2·6	·39	·77	1·16	1·54	1·93	2·32	2·70	3·08	3·48	3·85
2·5	·40	·80	1·20	1·60	2·00	2·40	2·80	3·20	3·60	4·00
2·4	·42	·83	1·25	1·67	2·09	2·50	2·92	3·34	3·75	4·17
2·3	·44	·87	1·30	1·74	2·18	2·61	3·05	3·48	3·92	4·35
2·2	·46	·91	1·37	1·82	2·28	2·73	3·19	3·64	4·10	4·55
2·1	·48	·95	1·43	1·90	2·38	2·86	3·33	3·81	4·28	4·76
2	·50	1·00	1·50	2·00	2·50	3·00	3·50	4·00	4·50	5·00
1·9	·53	1·05	1·58	2·10	2·63	3·16	3·68	4·21	4·73	5·26
1·8	·56	1·11	1·67	2·22	2·78	3·37	3·89	4·45	5·00	5·56
1·7	·59	1·18	1·76	2·35	2·94	3·53	4·12	4·70	5·29	5·88
1·6	·63	1·25	1·88	2·50	3·13	3·75	4·38	5·00	5·63	6·25
1·5	·66	1·33	2·00	2·66	3·32	4·00	4·66	5·33	6·00	6·66
1·4	·72	1·42	2·14	2·86	3·58	4·28	5·00	5·72	6·40	7·14
1·3	·78	1·54	2·32	3·08	3·86	4·64	5·40	6·16	6·96	7·70
1·2	·82	1·66	2·50	3·34	4·18	5·00	5·84	6·67	7·50	8·34
1·1	·92	1·82	2·74	3·64	4·56	5·46	6·38	7·28	8·20	9·10
1	1·00	2·00	3·00	4·00	5·00	6·00	7·00	8·00	9·00	10·00
·9	1·12	2·22	3·34	4·44	5·56	6·74	7·78	8·90	10·00	11·12
·8	1·26	2·50	3·76	5·00	6·26	7·50	8·76	10·00	11·26	12·50
·7	1·44	2·84	4·28	5·72	7·16	8·56	10·00	11·44	12·80	14·28
·6	1·64	3·33	5·00	6·68	8·36	10·00	11·68	13·34	15·00	16·68
·5	2·00	4·00	6·00	8·00	10·00	12·00	14·00	16·00	18·00	20·00

The time required to traverse any distance can be readily obtained from this table.

EXAMPLE.—Required the time taken to traverse $13\frac{1}{2}$ miles at 2·3 miles per hour.

Time for 10 miles at 2·3 miles per hour	..	..	4·35
,, ,, 3 ,, ,, ,,	..	..	1·30
,, ,, $\frac{1}{2}$ mile ,, ,,	..	..	·22
Time for $13\frac{1}{2}$ miles at 2·3 miles per hour	..	=	5·87

19. GAIN FROM ECHELONED CAMPS.

It is evident from the formula that the mobility may be increased by the use of camps echeloned along the road, while food and shelter are also more easily procured.

With homogeneous columns the gain C is equal to the length of road along which the camps are echeloned.

With columns of troops accompanied by second-line transport, the usual case, the gain depends largely on the order of march, and the position assigned to the transport. The gain is the length of column in order of march in rear of the leading vehicle of the second-line transport, less that belonging to the leading camp.

The gain C can best be seen from the following diagrams, in which A, B, and D are three bodies of troops using separate camps, and *a*, *b*, and *d* represent their second-line transport.

In the first diagram the second-line transport is placed in its usual position in the rear, and the gain C is as shown.

In the second figure A and B represent all the fighting troops necessary to commence and develop an action, and are followed on the march by their second-line transport *a* and *b*; D represents those units not required till a later stage, such as ammunition columns, etc. It will be seen that the gain C is much increased, and that the same column would have considerably greater mobility.

This order of march can be used without difficulty on broad roads, when the troops in rear, D in the figure, can pass the second-line transport, *a* and *b*, of the troops ahead, but on narrow roads might be objectionable when near the enemy.

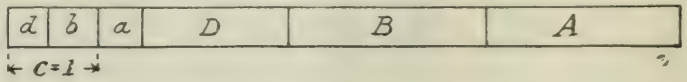


FIG. 1.

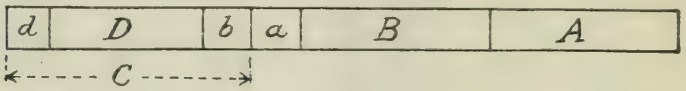


FIG. 2.

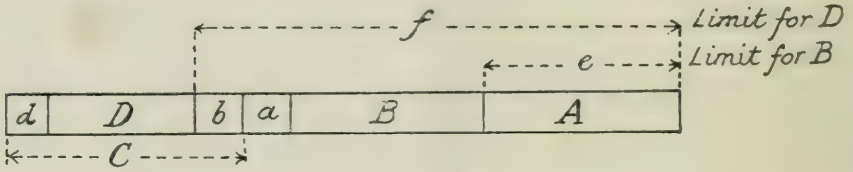


FIG. 3.

There is often considerable latitude in spacing the camps, as the full gain, C, can be obtained provided the camps are not spread over a distance less than C, or over a distance greater than the length of column which, in order of march, moves ahead of the camp in question.

For instance, in *Fig.* 3 the full gain C can be obtained provided the camps are not spread over a distance less than C, or over a greater distance than *f*, provided also that the camp of B is not further from the camp of A than the distance *e*.

20. USE OF FORMULA FOR SHORT COLUMNS.

For the purpose of this section, the expression Short Column is understood to mean one which is shorter than the distance marched.

EXAMPLE 7.—The road has a factor of ·9, both for troops and transport, and a mean width of 20 ft. There are 10 miles of troops (with their first-line transport), followed by 5 miles of second-line transport (horsed vehicles), including as such any troops which from their position in rear must conform to the rate of the transport.

The gain, C, from echeloned camps is 4 miles. How far could the column march in 14 hours ?

The case is that of a mixed column, so Formula 2 must be used.

L=10 ; K=1·3 ; KL=13 ; so r=2·27 from Table V.

L′=5 ; K=1 ; KL′=5 ; so r'=2·26 from Table V.

But R′F′=2·75×9=2·47 which is greater than r by ·2 of a mile an hour.

So the true value of r' is 2·26 – ·2, or 2·06 miles an hour.

Substituting in Formula 2 :—

$$\left(14-\frac{10}{2\cdot27}\right)\times 2\cdot06-5+4=\mathrm{M}.$$

From Table VII. we see $\frac{10}{2\cdot27}$=4·4 approximately.

So
$$(14-4\cdot4)\times 2\cdot06-5+4=\mathrm{M}.$$
$$19\cdot8-1=\mathrm{M}=18\cdot8 \text{ miles}.$$

The march theoretically possible is 18·8 miles, no allowance being made for rest-halts. In practice rest-halts would be necessary for a march of this length, and would reduce the actual march possible in the time to 16·7 miles.

21. USE OF FORMULA FOR LONG COLUMNS.

Long columns are here understood to be longer than the distance to be marched.

In such cases the march cannot be calculated directly but may be obtained by interpolation. This is due to the fact that r and r' now depend on M which is unknown.

Assume one or more values of M in order to obtain a value for r and r', and interpolate. If the correct value of M be assumed it will agree with the value calculated from the formula.

EXAMPLE 8.—The road has a factor of ·9 and a mean width of 20 ft. There are 10 miles of troops followed by 5 miles of second-line transport (including such troops as conform to the latter's rate). This division is followed by a second of the same composition which must also conform to the rate of the second-line transport preceding it. If concentrated camps are used, how far could the force march in 14 hours ?

Here L=10 ; L′=20 ; C=O.

Assume a march of 5 miles.

For troops M=5 ; K=1·3 ; KM=6·5 ; r=2·49.

For transport M=5 ; K=1 ; KM=5 ; r'=2·24.

It will be noted that r is greater now than R′F, so r' need not be reduced.

Interpolating in Formula 2 :—

$$\left(14-\frac{10}{2\cdot49}\right)\times 2\cdot24-20=\mathrm{M}.$$
$$(14-4)\times 2\cdot24-20=\mathrm{M}=2\cdot4 \text{ miles}.$$

The actual march will lie between the assumed value 5 miles, and the calculated value 2·4, and the mean of these 3·7 miles should be approximately correct.

This can be verified by calculating for a march of 3·7 miles.

For troops M=3·7 ; K=1·3 ; KM=4·8 ; r=2·55.

For transport M=3·7 ; K=1 ; KM=3·7 ; r'=2·34.

Interpolating in Formula 2 :—

$$\left(14-\frac{10}{2\cdot55}\right)\times 2\cdot34-20=\text{M}.$$

$$(14-3\cdot92)\times 2\cdot34-20=\text{M}.$$

$$23\cdot6-20=\text{M}=3\cdot6 \text{ miles}.$$

22. CONDITIONS AFFECTING THE LENGTH OF MARCH.

When the marches are long, additional halts, for rest, must be allowed, otherwise the troops cannot maintain their normal rates of marching, or else arrive in camp unduly fatigued.

In war, troops are frequently called on to make abnormal efforts but the undue exertion involved increases the march casualties, and if persisted in, seriously undermines the efficiency of the force. It is thus important to clearly realize what constitutes an abnormal effort, as such should not be demanded unless absolutely necessary, or because it promises proportionately great results.

A normal effort may be defined as one which does not tax the strength of the individual to a greater extent than can be made good by a proper night's rest and adequate food. There are thus two considerations involved, what constitutes a good march, and what time should be allowed in camp, billet or bivouac, for rest, etc.

A march may further be delayed by obstacles *en route* such as exceptionally bad pieces of road or by crossing fords, military bridges, etc., for which allowance should be made. The delays due to these vary considerably, but are much more marked on an otherwise good road than on one which is generally inferior.

23. REST-HALTS.

The normal rate, R, for the head of the column on a good standard road allows for the short periodical halts usually given ; the rate, r, for the rear of the column allows for any halts necessary for closing up ; but if the march exceeds 5 hours for the head of the column additional rest-halts are necessary, to prevent undue fatigue. The simplest method of allowing for such halts is to assume that for every additional 6 hours marching for the head of the column 4 hours should be allowed for rest-halts.

It must be noted that T in Formulæ 1 and 2 expresses the actual

hours marching, and takes no cognizance of rest-halts. Thus, if these be allowed, their duration must be added to T in order to find the total time required for the march.

It saves time and trouble in calculation to have T express the total time, and this can readily be done by assuming a theoretical increase of the march to allow for the rest-halts, as the latter depend on the length of march and not on the total time reckoned from the hours when the leading troops move off till that at which the rear of the column reaches its camp for the night.

The procedure is as follows :—

(*a*). If the length of march be known :—

If M be less than $5 \times RF$ no rest-halts are required.

If M be greater than $5 \times RF$ by x miles, make M in the formula equal to $5 \times RF + \frac{10}{6}x$, when T will correspond with the total time required.

(*b*). If the time available be known, and the march is to be determined :—

Calculate M from the formula in the usual way.

If M, so found, does not exceed $5 \times RF$ no further correction is necessary.

If M be greater than 5RF by, say, x miles, the actual march, allowing for rest-halts, which can be accomplished in T hours is $5 \times RF + \frac{6}{10}x$ miles.

EXAMPLE 9.—We saw in Example 7, p. 21, that the division could theoretically march 18·8 miles on a road which had a factor of ·9. Now $5 \times RF = 5 \times 3 \times \cdot 9 = 13 \cdot 5$ miles, which is 5·3 miles less than the theoretical march possible.

The actual march is accordingly $13 \cdot 5 + \frac{6}{10}5 \cdot 3$, or 16·7 miles.

24. LIMIT OF INDIVIDUAL EFFORT.

A normal march for troops should not ordinarily exceed $7 \times RF$ miles, though this may be increased to $8\frac{1}{2} \times RF$ miles for one or two days in succession, if preceded or followed by shorter marches. For transport, the normal march may be from $8 \times R'F'$ to $9 \times R'F'$ miles. Anything in excess of the above partakes of the nature of forced marching.

For *Forced Marches* the above limits may be considerably exceeded, but if pushed to the full limit of endurance must be followed by a complete day's rest.

In one day the limit for a forced march is 12RF to 13RF.

For two days in succession, 10RF to 11RF the first day, and $10R(F - \cdot 1)$ to $11R(F - \cdot 1)$ the second day.

In either case a normal march may follow after a night's rest, but the value of F must be again reduced by ·1, and a full day's rest must then follow.

25. PERIOD REQUIRED IN CAMP, BILLETS, OR BIVOUAC.

This period, including the time required for sleep, cooking and partaking of food, care of animals, loading up, etc., is generally taken to run from 8 to 12 hours. For any body of well-trained troops occupying the same camp a fair allowance would be 10 hours clear from the hour the last unit of second-line transport arrived till the first unit of troops marched off.

The length of march possible for a group of such bodies (such as a division) using separate camps can be found by calculating that of the longest body, using Formula 2 and assuming r' is that for the rear of the division, to ensure adequate closing up, and taking the time available as 14 hours, reduced where necessary for any hours after dark. The period of rest for each body is not in this case simultaneous, as advantage is taken of the fact of their moving off in succession, so that the marching time for the division as a whole is in excess of 14 hours.

It is convenient, however, to be able to calculate the march of a division as a whole, and in this case the period in camp may be taken as 8 hours, counting from the time the last unit of the division reaches its camp for the night until the leading unit of the division moves off next morning, if separate camps are used. This would leave available for marching 16 actual hours, which must be reduced as may be necessary to allow for any hours after dark.

When a concentrated camp is used the period would be 10 hours, and the balance available for marching 14 hours.

26. METHOD OF ALLOWING FOR OBSTACLES.

The delay in time due to the passage of the obstacle by the column should be estimated, D. If the time available for the march is known, T, then calculate the march for a time T – D. If the time required for the march is to be found, calculate the time neglecting the obstacle, and to this add the delay D.

27. DELAY DUE TO AN OBSTACLE.

When the head of a column reaches an obstacle its rate is reduced, and enforced on the whole column, after any opening out has been made good, until the rear of the column in turn passes the obstacle. If L be the length of the column, x the length of obstacle, both in miles, r the rate of the rear of the column on the road, and Rf the rate due to the obstacle, and D the delay due to the obstacle in time, then

$$D = \frac{L+x}{Rf} - \frac{L+x}{r}.$$

On a good road the value of r will be higher than on a bad road, so D will be greater; in other words a given obstacle causes less delay on a bad road than on a good one.

Strictly speaking D should be reduced by the time taken in closing up. If the head of the column marches y miles before reaching the obstacle the opening out is $y\left(\frac{RF-r}{RF}\right)$ miles, and the time taken in making good this opening out is $\frac{y}{r}\times\left(\frac{RF-r}{RF}\right)$ hours. As this has to be deducted from D it is evident that a given obstacle exercises less influence if it occurs near the end of the march than at the beginning.

The above formula applies to homogeneous columns, but it is more difficult to estimate the delay in mixed columns, without calculating in detail.* If the rear of the troops enter the obstacle before the head of the transport arrives, there is no delay due to the troops, and D is due to the second-line transport only. If z miles of the troops have failed to enter the obstacle before the arrival of the second-line transport then D is due to $L'+z+x$ miles, L' being the length of second-line transport, and x the length of the obstacle, both in miles.

In practice it is not really necessary to consider the obstacle provided that f does not differ from the mean value of F by more than ·2 in the case of troops, or ·25 in the case of second-line transport.

---

* EXAMPLE.—The road has a factor of ·9 and a width of 20 ft. The column consists of 10 miles of troops, followed by 5 miles of second-line transport. What would be the delay due to 1 mile of bad road, with a factor of ·5: (*a*), if 4 miles from the starting place; (*b*), if 12 miles from the starting place?

For the troops on the road RF $=2\cdot27$, and $r=2\cdot27$.
For the transport on the road R′F′ $=2\cdot47$, and $r=2\cdot06$.
For the troops in the obstacle RF $=1\cdot5$.
For the transport in the obstacle R′F′ $=1\cdot37$.

The gross delay due to the obstacle is

$$\frac{10+1}{1\cdot5}-\frac{10+1}{2\cdot27}+\frac{5+1}{1\cdot37}-\frac{5+1}{2\cdot06}.$$

Using Reciprocals:—

Reciprocal of 1·5 is	·667
Reciprocal of 2·27 is	·441
Difference	·226, say ·23.
Reciprocal of 1·37 is	·730
Reciprocal of 2·06 is	·485
Difference	·245, say ·25.

Gross delay $=11\times\cdot23+6\times\cdot25=4$ hours.

To find the net delay due to the obstacle we must deduct the opening out expressed in time.

28. FACTOR FOR OBSTACLES.

The road factor for a bad section of road can be estimated by means of Table I. in the usual way and is called f to distinguish it from the road factor F for the road, as a whole.

Military bridges are generally assumed to increase the opening out by 50 per cent., which is practically to say that they have a factor of ·7. If the bridge is very solidly constructed this may rise to ·8, while if it is wanting in rigidity, or flotation, f may fall to ·6. Bad, or difficult, approaches may cause a reduction of ·1 to ·2 in each case.

The case of fords is more varied, but generally the above values of f will suffice for an approximation.

In all cases the deductions for unfavourable conditions, see Table I., must be made if necessary.

29. CONDITION OF MARCH AND COMPOSITION OF DIVISION.

On any given road, although the road factor, conditions, and time available be identical, the march may vary considerably according to the quality of the staff work, the order of march adopted, and the facilities afforded by the country for food and shelter.

For the purpose of this analysis we will assume the road to have a width of 20 ft., and a factor of ·9 for both troops and second line transport. We will further allow 9 hours in camp or billet, reckoned from the time the last unit reaches its resting place till the leading unit moves off next morning, an allowance which will admit of the

---

(*a*). When the obstacle is 4 miles from the start.

$$\text{Opening out } \frac{4}{2\cdot27} - \frac{4}{2\cdot7} + \frac{4}{2\cdot06} - \frac{4}{2\cdot47}.$$

Reciprocal of 2·27 = ·441
Reciprocal of 2·7 = ·370

Difference ·071

Reciprocal of 2·06 = ·485
Reciprocal of 2·47 = ·405

Difference ·08

Opening out = 4 × ·07 + 4 × ·08 = ·6 hours.
The net delay is accordingly 4 − ·6 = 3·4 hours.

(*b*). When the obstacle is 12 miles from the starting place.

$$\text{Opening out} = \frac{12}{2\cdot27} - \frac{12}{2\cdot7} + \frac{12}{2\cdot06} - \frac{12}{2\cdot47}$$

$$= 12 \times \cdot07 + 12 \times \cdot08 = 1\cdot8 \text{ hours.}$$

The net delay is accordingly 4 − 1·8, or 2·2 hours, provided the head of the column does not halt to allow of closing up before reaching the obstacle.

most unfavourably situated unit having six to seven hours' sleep. As we are allowing one hour more than is necessary, we may neglect the march from the road to and from camp or billet, provided these are situated not more than 1 mile from the road on either side.

There are thus 15 hours available for marching.

Assuming that the head of the column moves off at 6 a.m., and that there are 12 hours daylight with starlight nights, three of the hours marching are after dark, and are so equivalent to two hours by day. Thus the equivalent time available is 14 hours, reckoned by daylight.

Our suppositious division is 15 miles long, and consists of $13\frac{1}{2}$ miles of troops (accompanied by their first-line transport) and of $1\frac{1}{2}$ miles of second-line transport on horsed vehicles. Of the $13\frac{1}{2}$ miles of troops, 10 miles (A and B in the accompanying *Figures*) are required for the combat, the remaining $3\frac{1}{2}$ miles (E in the *Figures*) consist of such troops, ammunition columns, ambulance, etc., as are not wanted till a later period of the action.

The three bodies of troops A, B, and E are 5, 5, and $3\frac{1}{2}$ miles long respectively, except in *Fig.* 5 where their lengths are shown. The second-line transport appertaining to their bodies are *a*, *b* and *e*, each of which is assumed to occupy half a mile of road.

30. USING ONE CONCENTRATED CAMP.

This is the most unfavourable case. Preparations for the march begin at 4.30 a.m., the leading troops march off at 6 a.m., the last of the second-line transport arrives at 9 p.m., and the force is not completely settled for the night until 10.30 p.m.

The theoretical march possible is 14·8 miles, but as this exceeds 5RF, or 13·5 miles, rest-halts are necessary. The actual march is 14·4 miles.

31. ECHELONED CAMPS, TRANSPORT IN REAR.

By transport, in this, and succeeding cases, is meant second-line transport. This order of march corresponds to that shown in *Fig.* 1.

Provided the troops depend on their transport for food, etc., although the camps may be echeloned along as much as $12\frac{1}{2}$ miles of road, the gain C, as compared with a single concentrated camp, remains only 1 mile (see *Fig.* 1, p. 29).

The theoretical march would be 15·8 miles and the actual march, allowing for halts, say 15 miles.

32. FIGHTING TROOPS IN FRONT, FOLLOWED BY THEIR TRANSPORT.

The order of march is that shown in *Fig.* 2, p. 29.

Bodies A and B, comprising the 10 miles of troops necessary for combat, head the column and are followed by their second-line transport *a* and *b*.

The body E has to conform to the rate of the second-line transport in front of it, so the length of the latter becomes, for purposes of calculation, 5 miles.

The gain from echeloned camps is, in this case, $4\frac{1}{2}$ miles as shown. The theoretical march would be 19 and the actual march, allowing for rest-halts, 17 miles.

33. EACH BODY OF TROOPS FOLLOWED BY ITS TRANSPORT.

This order of march is shown in *Fig.* 4, p. 29. It will be observed that only half the combatant portion of the division is now concentrated at night, viz. A, while the remainder would be $5\frac{1}{2}$ miles in rear. This is a disadvantage for the leading division on a road, though the order of march might be suitable for others further to the rear.

The bodies B, E, *b*, and *e* must all conform to the rate of second-line transport.

The gain from echeloned camps would be $9\frac{1}{2}$ miles as shown.

The theoretical march would be 24·3 miles, and the actual march, allowing for rest-halts, 20 miles.

34. TWO-THIRDS OF FIGHTING TROOPS IN FRONT.

This order of march is shown in *Fig.* 5, and is intermediate between that given in *Figs.* 2 and 4 (see p. 29).

The balance of troops required for combat would be camped 4 miles in rear, while the proportion in front would be sufficient to open the action in the majority of instances.

In this case the gain from echeloned camps is 8 miles, the theoretical march 23 miles, and the actual march 19·2 miles.

35. POSITION OF SECOND-LINE TRANSPORT.

Provided the column is headed by sufficient troops to open the action and maintain themselves until the bodies in rear can be brought up, there is no real objection to a portion of the baggage being placed in a more forward position in the column, as shown in *Figs.* 2, 4, and 5, provided the road is wide enough for troops to pass transport if necessary, or if narrow is not enclosed, so that transport may be moved off the road to make way for troops.

The gain in mobility from putting the baggage of the leading bodies in a more advanced position, as shown, is considerable.

On a narrow enclosed road, however, the risk of getting troops blocked when their services were required at the front would be too great for a leading division, and the transport must be relegated to, or nearer to, the rear, with consequent loss of mobility.

It must further be noted that when the surface of any road is bad, the advantage due to altering the order of march is much reduced. In the present case if F′ for transport were ·7, the marches corresponding to *Figs.* 1 and 4 would be 13·7 and 14·7 miles respectively.

36. DEPENDING ON COUNTRY FOR FOOD AND SHELTER.

If the country is so fertile and populous that the troops can obtain proper shelter and food independent of their second-line transport, the length of march depends on what degree of concentration is considered necessary, and the distance over which the billets extend measured parallel to the road.

If the billets extended over 5 miles of road the actual march would be 17·3 miles, while with billets along 8 miles of road the march would be about 19 miles. In the extreme, and unlikely, case of divisions being billeted practically in column of route, the actual march would work out to 21·2 miles.

Fig. 6 shows the billets extending over 10 miles of road, when the actual march is 19·4 miles.

Order of March.

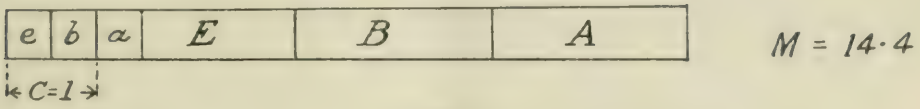


FIG. 1.

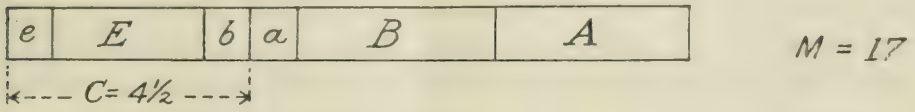


FIG. 2.

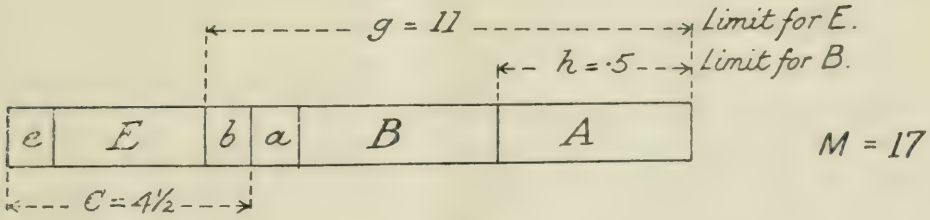


FIG. 3.

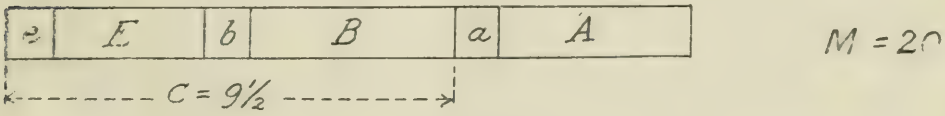


FIG. 4.

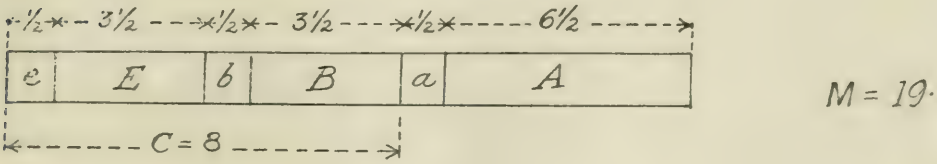


FIG. 5.

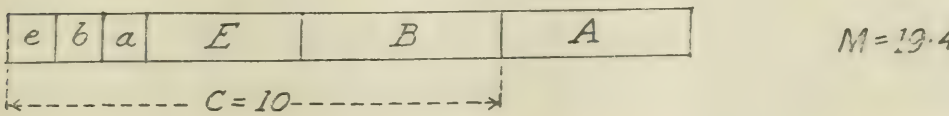


FIG 6.

37. DEGREE OF CONCENTRATION.

From *Fig.* 3, p. 29, we can find the limits within which the camps or billets of the various bodies must lie in order that the full gain C can be obtained.

The camp B must not be nearer that of A than half a mile, the road space occupied by *a*, not further from it than *h*, 5 miles, the length of troops which precede B on the march.

Similarly the camp of E must not be nearer that of A than $4\frac{1}{2}$ miles, nor further from it than *g*, or 11 miles.

Should either B or E fail to reach their allotted camps one day, it need not decrease their march next day, provided the above limits are not exceeded.

The actual degree of concentration permissible for a division must vary with the circumstances and its proximity to the enemy. It would rarely be necessary to close its camps to within 4 miles, and is hardly desirable to extend them over 8 miles.

38. TWO OR MORE DIVISIONS ON ONE ROAD.

When two, or more, divisions have to use the same road, the leading division can march as usual, but any behind may be delayed according to the distance which separates them, as well as by conforming to the rate of the second-line transport of the leading division.

Assuming as before that the road has a factor of ·9 and a width of 20 ft., that 4 miles can be gained from the use of echeloned camps, and that each division is headed by 10 miles of troops followed by 5 miles of second-line transport, including such troops as must conform to the transport rate, and lastly that there are 14 hours available for marching.

If the distance between the first and second division, leading camp to leading camp, is rather more (roughly 10 per cent.) than the length of a division, the second is not interfered with by the first, and each can make a theoretical march of nearly 19 miles, or an actual march, allowing for rest-halts, of nearly 17 miles.

If however the two divisions are concentrated in a single camp, we have to deal with the march of a long column consisting of 10 miles of troops and 20 miles of second-line transport, as the second division must conform to the transport rate, and the actual march possible in 14 hours is only 3·7 miles.

These two cases are susceptible of easy calculation, see Examples 7 and 8, pp. 20 and 21. But for intermediate distances it is best to adopt a graphic solution, by means of a "March-Distance" Diagram which can easily be constructed on a ruled page in any officer's pocket-book.

39. TO CONSTRUCT A MARCH-DISTANCE DIAGRAM.

The following data must first be decided, or calculated :—

Decide on the maximum value of C which we are prepared to employ, say C=8, which corresponds with the order of march in *Fig.* 5.

Then calculate :—

For first division :—

Theoretical march with C=8, which is 23 miles.
Actual march, allowing rest-halts, which is 19 miles.
Theoretical march with concentrated camp, which is 15 miles.
Actual march with concentrated camp, which is 14 miles.

For second division :—

Distance apart of divisions to avoid interference, which is $15+\frac{1}{10}\times 15=16{\cdot}5$ miles.
Moving independently, with C=8, theoretical march 23. actual 19 miles.
Actual march with both divisions in a concentrated camp, 3·7 miles.

For third division :—

Distance to avoid interference, as above, 16·5 miles.
Moving independently, C=8, theoretical march 23 miles, and actual march 19 miles.
With all three divisions in one concentrated camp, the march is −9·5 miles.*

Construction of diagram :—

Draw two scales of miles at right angles to each other, the horizontal one for march, and the vertical one for distance between divisions plus C.
Also draw a vertical for a march of 5RF, in this case 13·5 miles.

For first division :—

For distance 0, lay off b' and b, 15 and 14·4 miles.
For distance 8, lay off a' and a, 23 and 19 miles.
Join ab.
The march for any value of C intermediate between 0 and 8, can be found by drawing a horizontal through C on the distance scale until it meets ab, and from the point of intersection dropping a vertical to the scale of miles, when the march can be noted.

* In this case the value of M as found from Formula (2) is negative, which means that the length of column is so great that it cannot wholly defile from camp into column of route in the time available. When it is apparent that this is the case take r=RF, and r'=R'F'.

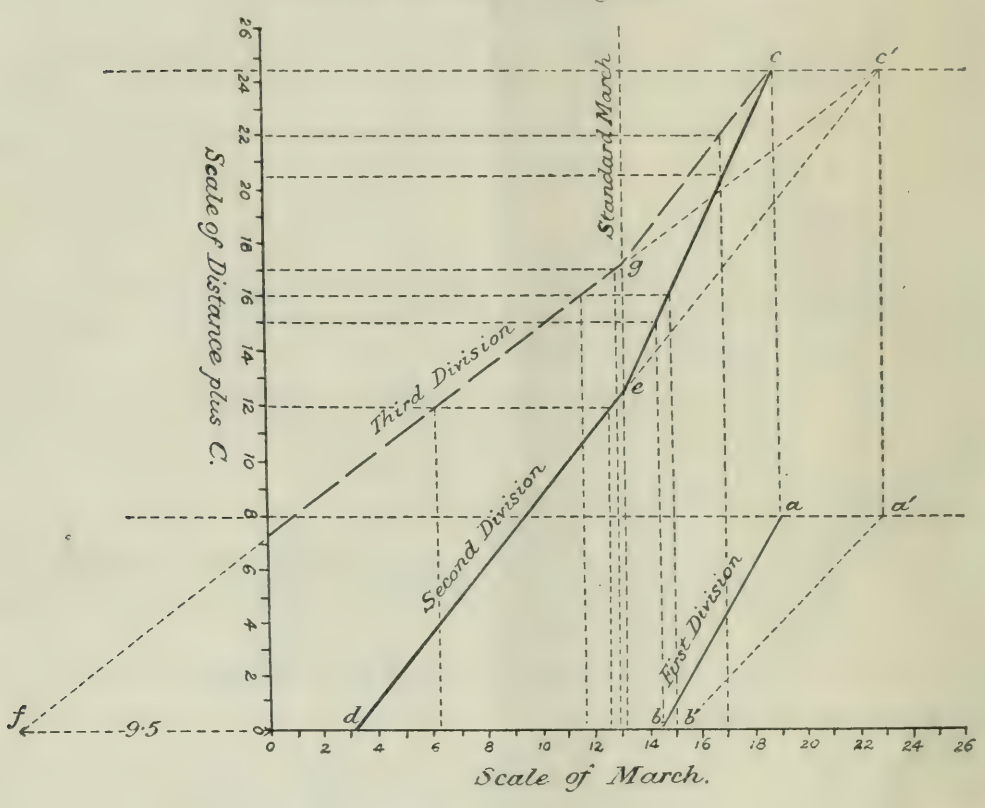
For second division :—

For distance 0, lay off $d=3{\cdot}7$ miles.
For distance $24\frac{1}{2}$, viz. $16{\cdot}5+8$, lay off c' and c, 23 and 19 miles.
Join dc', cutting the standard march at e.
Join ce.
The line dec is that for the second division.

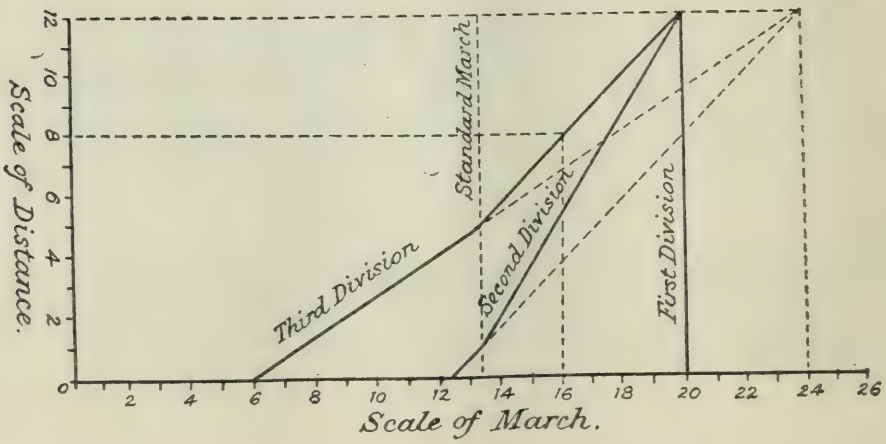
For the third division :—

For distance 0, lay off to the left, $f=9{\cdot}5$ miles.
For distance $24\frac{1}{2}$, lay off c' and c, 23 and 19 miles.
Join fc', cutting the standard march at g.
Join cg.
The line fgc is that for the third division.

March-Distance Diagram.



Concentration Diagram.



40. APPLICATION OF MARCH-DISTANCE DIAGRAM.

If we want to find the march possible when the divisions are 9 miles apart, leading camp to leading camp, and the gain from echeloned camps is 3 miles, draw a horizontal through 12 (*i.e.* 9+3) on the distance scale and drop verticals from the points where it cuts the division lines. The marches can then be read on the scale of march in miles.

For the second division it is $12\frac{1}{2}$ miles, and for the third division $6\frac{1}{4}$ miles.

If the distance between divisions were 12 miles, and C=4, draw a horizontal through 16 (*i.e.* 12+4), on the distance scale, and drop verticals as before. The possible march would now be, for the second division 15 miles, and for the third division 11·8.

The diagram is equally applicable when the distances between divisions are unequal. If for instance the distance between the first and second divisions was 9 miles with 3 as a value of C, while the distance between the second and third divisions was 12 miles with 4 as the value of C, draw a horizontal through 12 to get the march of the second, and through 16 to get that of the third division. The march of the second division would be $12\frac{1}{2}$ miles, and that of the third division 11·8 miles.

Under no circumstances, however, can the march of any division exceed what it could do if marching independently.

It will be noted that the diagram gives no march for the third division until the distance plus C exceeds 7 on the scale. This indicates that below that the full 14 hours available cannot be utilized, and the third division must limit its march to the clear space of road between its leading unit and the rear of the second division.

The diagram can equally be used to find what distances, or order, of march to adopt to secure any required mobility.

If, for instance, the force of three divisions is required to march 17 miles a day. Raise a vertical from 17 on the march scale to cut the lines for the second and third divisions and see what the points of intersection give on the distance scale. These are 20·5 for the second division, and 22 for the third division. If now we adopt orders of march giving C=5·5 miles for the second division, and C=7 for the third division, we find that the force can move 17 miles a day with distances of 15 miles between divisions.

41. DIVISIONS STARTING AT DIFFERENT HOURS.

So far, we have assumed that each division starts at 6 a.m. and that its rearmost unit reaches camp at 9 p.m., the last three hours being after dark on a starlight night.

If, however, the leading division started before 6 a.m., and the

third division after 6 a.m., the effect would be the same as if the distances between the divisions were increased, with a consequent increase in the possible length of march.

Theoretically the totals of the variation in time may equal the period allowed in camp for rest, etc., but in practice only 4 to 5 hours may be utilized. It must further be noted that while an earlier start for the leading division, with a limit of 3 hours' variation, does not affect the time available, every hour by which the start of the third division is delayed, means one hour's march transferred from daylight to darkness, when the rate of march is slower.

Thus for earlier starts of x hours take the distance gained as xr'.

For later starts of x hours take the distance gained as $\frac{2}{3}xr'$.

If the leading division moved 1·6 hours earlier, or at 4.24 a.m., while the third division moved off 2·4 hours later, or at 8.32 a.m., the increase of distance would be $1{\cdot}6r'$, or $1{\cdot}6\times 2$, viz. 3·2 miles for the second division, and $\frac{2}{3}\times 2{\cdot}4\times 2$, viz. 3·2 miles for the third division.

We saw that the force could march 17 miles a day if the division were 15 miles apart, provided that the values of C for those divisions were 4·5, 5·5, and 7 miles respectively.

Utilizing the expedient of varying the hours for starting, to the extent given above, we find that the same march could be attained although the distances between divisions were reduced to $15-3{\cdot}2$, or 11·8 miles.

Altering the hours of starting is of value in so far as it allows of the actual distances between the camps of the various divisions being decreased, while retaining any required degree of mobility.

42. COMBINED MARCHING.

When a large force is marching, use must be made of a number of parallel roads with two, or more, divisions on each road, unless such roads are so numerous and so close together, that a single division can be allotted to each, without danger of its being unduly extended when deployed for action.

In combined marching it is not only necessary to consider the mobility attainable, but also the power of concentration, and facility of supply.

43. POWER OF CONCENTRATION FOR BATTLE.

While still at a distance from the enemy the longer the marches possible with ordinary exertion, the greater the power of manœuvre. But on nearing the enemy power of concentration is essential. When actually concentrating for battle the troops alone need be considered, and the second line transport may be left behind, to follow on later. In such a case, take one hour more than the actual time available, to allow for more rapid marching and for some curtailment of halts.

Further, as we are dealing with homogeneous columns, when C = depth of camps, the effect is nearly the same as if we used the formula $Tr - L = M$, and assumed each division concentrated in its leading camp.

The minimum distance between divisions, leading camp to leading camp, for full mobility is $L + \frac{1}{3}L$, when L is the length of troops for one division to be concentrated.

Suppose that it is required to concentrate 10 miles of troops from each of the three divisions marching on the same road, in 14 hours.

Calculate as before, using $T = 14 + 1 = 15$.

Single division, theoretical march 24, actual march 20 miles.

Two divisions concentrated, actual march 12·5 miles.

Three divisions concentrated, 6·2 miles.

Distance for full mobility, $10 + \frac{1}{3}$ 10, or 12 miles.

Construct a "Concentration" diagram from the above data, on the same general lines as the "March-Distance" diagram already described, see Section 39.

It will be seen that the 30 miles of troops can be concentrated in 14 hours, provided the distance between heads of divisions does not exceed 8 miles. For, with a distance of 8, the third division troops can march 16 miles, which is equal to the sum of the distance separating the divisions.

44. Mobility Retaining Full Power of Concentration.

By the use of the two diagrams for "March-Distances," and for "Concentration," it is possible so to arrange the distances between heads of divisions as to secure the maximum mobility consistent with the power of concentrating for battle.

We have already seen that the force could march 17 miles a day, when the distances between heads of divisions is 16·5 miles, and the order of march as in *Fig.* 2. From the "Concentration" diagram we see that 10 miles of troops from any division can march 20 miles in 14 hours, provided the distances between divisions is 12 or more miles. With 16·5 miles between divisions, the troops of the second division could be concentrated on the first division by 1 p.m.,* the head of the column being up by 9 a.m. The third division troops could not however reach the first until 5 a.m. next morning, and then in a condition of extreme exhaustion after a hard forced march. A distance of 16·5 miles between divisions thus gives high mobility, but a low power of concentration where three divisions are concerned.

* This assumes that the troops of the second division, which reached camp at 9 p.m., could march at 11 p.m. after a meal; this would allow them on an average six hours in camp after their previous march, as the head of the column arrived about 5 p.m.

From the "Concentration" diagram we saw that the troops of the second and third divisions could be concentrated on the first in 14 hours, provided that the distance between heads of divisions did not exceed 8 miles. The rear of the troops from the third division would be up at 3.30 p.m., the head at 1.30 p.m. Adhering to the order of march given in *Fig.* 2, where C=4·5, the marches possible for the second and third divisions as a whole, would be that corresponding to 12·5 miles on the distance scale in the "March-Distance" diagram.

The march would accordingly be, for the second division, 13·5 miles, and for the third division 7·5 miles. The rate of advance of the whole force as a whole would be $7\frac{1}{2}$ miles a day, so that this arrangement, while giving greater power of concentration, is deficient in mobility.

By the aid of the two diagrams we can alter the distances between divisions, the order of march, and the hours of starting so as to secure much better results.

Assume the distance between the heads of the first and second divisions to be 7 miles, and that between the second and third to be $10\frac{1}{4}$ miles. From the "Concentration" diagram these correspond to a march of $17\frac{1}{4}$ miles for the second, and $18\frac{1}{4}$ miles for the third. As the total distance between the heads of the first and third divisions is only $17\frac{1}{4}$ miles, the latter division can march the distance and make good the two $\frac{1}{2}$-mile gaps which occur from part of the second-line transport dropping out.

If the leading division starts 2 hours earlier and the third division $2\frac{1}{2}$ hours later, this is equivalent to increased distances of 4 and 3·3 miles respectively for the second and third divisions, bringing the total up to 7+4, or 11 miles for the former, and 10·25+3·3, or 13·5 miles for the latter.

If now the order of march of the third division is altered so that C=6, and that of the second so that C=4·8, the marches will correspond to 15·8 and 19·5 on the distance scale of the "March-Distance" diagram. In both cases the march will be 15 miles.

The rate of march will be doubled while full power of concentration will be retained. Thirty miles of troops can be concentrated in 14 hours, the last troops of the third division getting up at 6 p.m. and its leading troops at 2 p.m.

45. MOBILITY WITH HIGH POWER OF CONCENTRATION.

If we are content with concentrating the troops of the second and about half those of the third divisions, making with the first a total assemblage of 26 miles of troops, still better results as regards mobility can be secured.

Assume the distance between the first and second, and second and

third divisions to be 11 and 13 miles respectively. The troops of the third can now move 20 miles in 14 hours when concentrating for battle, so that 6 miles of troops could get up in this time, the total distance to be covered being 11+13, or 24 miles, for all to arrive.

Further, assume the order of march for the two rearward divisions to be as in *Fig.* 4, but take C=6. If the leading division starts 1·6 hours earlier, and the third 2·4 hours later, this is tantamount to an increase of distance of 3·3 miles.

The equivalent distances between divisions become 11+6+3·3, or 20·3 miles for the second, and 13+6+3·3, or 22·3 miles for the third divisions.

From the "March-Distance" diagram we find that the resulting march would be 17 miles in each case.

The rate of advance of the force would accordingly be 17 miles a day, while it retained the power of concentrating 26 miles of troops in 14 hours, or by 6 p.m.

46. VARIATIONS IN LOCATION OF CAMPS OR BILLETS.

We saw in Section 37, when considering the order of march, that the camps, or billets, of the bodies B and E might be spaced within fairly wide limits without affecting the value of C, so that the distance which could be moved the following day would remain as calculated. But if either of the three bodies have to stop short of the points which they are intended to reach, the consequent loss can only be made good by a longer subsequent march.

In practice it is impossible to hope that the distances between divisions, and the positions of camps and billets can always be arranged according to theory. Indeed departures from theory are the rule and not the exception. The general rate of advance would accordingly fall short of that arrived at by calculation, unless the data chosen admit of a certain elasticity.

This elasticity is given by the facts, that the period allowed in camp may be reduced by one hour without detriment, the full value of C for the order of march is not utilized, and the hours of starting may be still further varied to the extent of an hour without disadvantage.

For instance in the example given in the last section, where the force could advance 17 miles a day, the curtailment of the period in camp by one hour, would, allowing for decreased rate at night and for rest-halts, add 1 mile to the march. The full value of C for the order of march is 2 miles greater than taken, and a variation of one hour in the hours of starting would be equivalent to an increase of distance of 1·3 miles: the sum of these two last would admit of the march being increased by 2 miles at least. Thus, while

the march is calculated as 17 miles a day, it can be increased, on occasion, to 20 miles, without unduly fatiguing men or animals, and there are accordingly 3 miles of latitude in the spacing of individual camps or billets.

When altering the hours for starting it is necessary that orders should be issued for the whole force on one road, otherwise the gain of distance may be rendered illusory by the independent action of any division. Rectification of position within the division itself may be carried out by slightly curtailing the period in camp, or by making fuller use of C.

It may be noted that still further elasticity is obtained by altering the order of march, so as to increase the actual value of C; the gain from this procedure affects the leading body of a division the day it is adopted, and bodies in rear the subsequent day.

By a judicious application of the principles a high rate of mobility may be secured for any force, while retaining a sufficient elasticity in the location of camps or billets, to satisfy the requirements of practice.

47. SUPPLY AS AFFECTING MOBILITY.

The question of supply is a large, important, and technical subject, to which it would be undesirable to refer except very briefly in so far as it affects the mobility of the force.

If a force can wholly subsist on the country traversed, its mobility is practically unfettered. If it carries with it sufficient supplies to enable it to reach a district when it can provide for itself, it is independent of its depôt as regards food.

But as long as a force is dependent on obtaining supplies from a depôt, whether a fixed magazine, or a movable park, or a railway station which may be chosen for its proximity to the camps or billets, the supply column by which it is linked to this depôt has a direct bearing on the mobility.

For every day's supplies carried by the supply column the force can operate at half a day's march from the depôt, reckoned according to the powers of the class of transport used. For instance on a road with ·9 as a factor, and a width of 20 ft., when a supply column of motor lorries is used, the most distant unit to be supplied must not be more than 32 miles from the depôt, be it park or railway station. If this distance must be exceeded, then the supply column must contain sufficient vehicles to carry two days' supplies for the unit, and the unit must have sufficient transport to carry one day's extra food, or else the length of march for the force must be reduced.

When a large force is advancing by parallel roads, there is not much difficulty in supplying it, provided there is not more than one division on a road. With two divisions on each road, supply from the rear is more difficult and requires more nicety of staff work, as

the time during which the roads are clear of troops is limited. With three divisions on one road supply from the rear becomes almost impossible owing to the limited time available, unless the roads are sufficiently wide to allow the supply columns to pass the troops on the march, and even then is rendered very difficult owing to the great depth of road occupied by the camps or billets.

When the supply columns draw their stores from an adjacent railway station, changed from day to day as the force advances, the station selected should lie about midway between the prospective camps of the first and third divisions, when the supply service can be carried out both backwards and forwards more or less simultaneously.

Or, an alternative method is, to restrict the force on certain of the roads to a single division, strengthened, if necessary, by additional brigades, when such roads can be used by the supply columns to get more rapidly forward, and then by lateral routes provide for the division on the neighbouring roads.

If other military considerations render both these systems inadvisable, and the supply must be from the rear, while full mobility is required, the only alternative is to double the strength of the supply columns, and further allocate additional transport, to carry an extra day's food, to the leading divisions, unless the latter can depend on obtaining supplies locally, to the extent of half their daily requirements.

When two, or more, echelons of troops are marching on a single road, and neither railways nor mechanical transport are available, while they are dependent on supplies from the rear, they can use their full mobility for the number of days' food carried with each echelon, less the time it would take for the supply park to reach them. Or they must draw on the latter from day to day, in which case the march must be reduced to $5R'F'$, when R' and F' are the rate and road factor for the class of transport employed, $5R'F'$ being a little more than half a normal march for the transport; they must further have their second line supply section so arranged, that the second echelon can pass on one day's food for the first, and the third echelon one day's food for both those in front.

This question is however beyond the scope of these notes, which aim at explaining certain principles and methods of analysis to assist officers in dealing with that branch of logistics which concerns movements by roads.

48. FORCED MARCHING.

Previous sections have been almost entirely confined to ordinary marches, in which the day's work does not demand a greater expenditure of strength from the individual than can be made good by adequate food and rest. Under these circumstances ordinary

marches may be continued day after day, with an occasional day of rest, when repairs to clothing, harness, equipment, etc., may be attended to, and minor irregularities may be rectified.

Forced marching comes under a very different category, as the individual is being taxed beyond his normal strength and beyond his normal powers of recuperation. While ordinary marching may be likened to living on the interest on capital, forced marching would correspond to the spendthrift, who used both capital and interest. A force which habitually employed forced marches would soon be as bankrupt of strength as the spendthrift of resources. While with ordinary marching the casualties with good management should not exceed 2 per 1,000 per day, forced marches may easily increase these casualties tenfold.

For these reasons forced marches should be used sparingly, and never unless the prospective advantage outweighs the certain loss of efficiency, and then only after every arrangement has been carefully and minutely provided for by the staff to reduce the great and unavoidable hardships entailed.

Still, as war cannot be made by hard and fast rule, forced marches are frequently necessary, but can usually be carried out by only a portion of the force and for strictly limited periods of time.

49. NATURE OF FORCED MARCHING.

Bearing in mind that a forced march is one which drains the reserve of individual strength to a greater extent than can be restored by nature in the period allotted for rest, we find that a march may be classed as forced from several reasons, either separately or in combination. The actual length of march may exceed the normal limit of individual strength, see Section 24; while this limit is not exceeded the period allowed for rest and recuperation may be too short to allow nature to replenish the energy expended; or lack of sufficient food may produce the same result. Want of proper shelter in inclement weather may so greatly sap the strength of the men and animals as to render forced a march which under more favourable conditions would be well within their power.

The limits of individual effort are dealt with in Section 24, and the period required for repose, when the forced march is to exceed 24 hours, in Section 25, while deficiency of food or inadequate shelter may be allowed for by decreasing the road factor, see Section 3. Rest-halts on long marches are considered in Section 23; for marches over 5RF miles these may be reduced from $\frac{4}{10}$ to $\frac{3}{10}$ when the movement is carried out under a great stimulus, such as concentrating for battle, but usually the full proportion should be allowed, as a forced march makes great and sometimes cruel demands on the individual, when it is difficult for exhausted nature to march to scheduled time.

In the majority of cases there is little difficulty in deciding whether a given march should be classed as ordinary or forced, but others are more difficult to define, as, though apparently normal, they may actually be, or easily merge into, forced marches, owing to comparatively slight modification in the conditions under which they are carried out.

50. LENGTH OF FORCED MARCH IN ONE DAY.

This can be best shown by means of an example.

EXAMPLE 10.—The road has a factor ·9, and a width of 20 ft.; there are 12 hours daylight, and starlight nights. A column of troops, 10 miles long, is echeloned along 4 miles of camps. How far in front of its rearmost camp could it concentrate in 24 hours under favourable circumstances, starting at 6 a.m. after a good night's rest?

With 12 hours daylight, and starlight nights, 24 hours are equivalent to $12+\frac{2}{3}12$, or 20 hours by day, see Section 15.

From Table IV., K=1·3, so KL=13, and $r=2·27$, from Table V.

Substituting in Formula 1, Section 18, and taking C=4 :—

$$20\times 2·27-10+4=M=39·4 \text{ miles theoretical.}$$

Allowing for rest-halts, Section 23, 39·4 miles theoretical are equivalent to $13·5+(39·4-13·5)\frac{6}{10}$, or 29 miles actual.

The column could be concentrated 29 miles ahead of its rearmost camp. This is not in excess of the limit of individual endurance, which is 13RF, or 35 miles.

51. LENGTH OF FORCED MARCH IN TWO DAYS.

The method of calculation will be illustrated by an example :—

EXAMPLE 11.—The road has a factor of ·9, and a width of 20 ft.; there are 12 hours daylight, and bright starlight nights. A column of troops, 10 miles long, is echeloned along 4 miles of camps. How far in front of its rearmost camp could it concentrate in 48 hours under favourable circumstances, starting at 6 a.m. after a good night's rest?

As the march is to be continued over one day, it is necessary to allow 6 hours' rest at night, and we will assume that questions of water supply, etc., compel the column to close up to 4 miles at night.

(1). *First Day.*—Time available $12+6\frac{2}{3}$, or 16 hours.

The other data are as in Example 10.

Substituting in Formula 1 :—

$$16\times 2·27-10+4=M=30·3 \text{ miles theoretical.}$$

Allowing for rest-halts, 30·3 miles theoretical are equivalent to 23·6 miles actual, which is within the limit of 10×RF or 27 miles.

(2). *Second Day.*—The full 24 hours is available, and is equivalent to 20 hours by day, but the factor must be taken as ·8, as this is a second forced march in succession, so that r falls to 1·87. C is 4.

Substituting in Formula 1 :—

$$20 \times 1{\cdot}87 - 10 + 4 = M = 31{\cdot}4 \text{ miles theoretical.}$$

The actual march is $5RF + (31{\cdot}4 - 5RF)\frac{6}{10}$. As 5RF is $5 \times 3 \times {\cdot}8$ or 12 miles, the actual march is 23·6 miles, which is within the limit of 12R (F − ·1), or 28·8 miles.

(3). *March in 48 Hours.*—The column could be concentrated 23·6+23·6, or 47·2 miles ahead of its rearmost camp in 48 hours, as the limits of individual endurance are not exceeded.

52. Force which can be Concentrated by a Forced March.

The length of column which can be concentrated in a given time can be obtained by the construction of a Concentration Diagram, Section 43, or by calculation. In the latter case two lengths of column being assumed, the length of march for each in the given time is calculated, and the correct length of column deduced by interpolation.

Or the length of column may be obtained by the use of the Capacity Table VIII., Section 53, without much calculation and with approximate accuracy.

53. Description of Capacity Table.

This table facilitates calculation by eliminating all consideration of K and r.

In the table will be found under different values of F, and opposite different widths of road, according to the formation adopted, the length of " column " which can march 5RF miles in 12 hours, using concentrated camps, or 5RF+C miles in 12 hours, if using echeloned camps with a gain C.

Plus, or minus, corrections are also given for each hour available over, or under, 12 hours. A correction is also given for each mile by which the march falls short of or exceeds the standard march, viz., 5FR with concentrated, or 5RF+C with echeloned camps.

A further plus correction is given to be used when the length of column, as deduced from the table, exceeds the length of march for which the column is calculated.

The table though designed to give the length of column which can march a given distance in a stated time, may also be used to find the length of march possible or the time required. The results are approximate only, but the error should not exceed 10 per cent., except in extreme cases.

VIII.—CAPACITY TABLE.

For Troops, accompanied by their First-Line Transport.

To find Length of Column to Accomplish a Given March in a Given Time.

Formation. File	Fours.	Width of Road.	Data.		F=1	F=·9	F=·8	F=·7	F=·6	F=·5	F=·4	F=·3
		Ft	Ft.									
12	24		Column (for 12 hours) ..		15·4	13·4	11·4	9·7	8·1	6·6	5·0	3·7
			One hour more	+	1·8	1·6	1·3	1·1	·8	·6	·4	·3
			One hour less	−	2·0	1·8	1·5	1·3	1·0	·9	·6	·5
			One mile more	−	·7	·7	·7	·7	·6	·6	·6	·6
			Add (L − M)	×	·3	·4	·4	·5	·6	·6	·7	·7
10	20		Column (for 12 hours) ..		14·2	12·3	10·4	8·8	7·3	5·9	4·5	3·3
			One hour more	+	1·7	1·4	1·1	1·0	·7	·5	·4	·2
			One hour less	−	1·9	1·6	1·3	1·2	·9	·6	·5	·4
			One mile more	−	·7	·6	·6	·6	·6	·5	·5	·5
			Add (L − M)	×	·4	·5	·6	·7	·7	·8	·8	·9
8	16		Column (for 12 hours) ..		13·1	11·3	9·5	8·1	6·6	5·3	4·0	2·9
			One hour more	+	1·5	1·2	1·0	·8	·6	·4	·3	·2
			One hour less	−	1·7	1·4	1·2	1·0	·8	·6	·5	·3
			One mile more	−	·6	·6	·6	·5	·5	·5	·5	·5
			Add (L − M)	×	·6	·7	·7	·9	·9	1·0	1·0	1·1
6	12		Column (for 12 hours) ..		12·2	10·4	8·7	7·4	5·9	4·7	3·5	2·6
			One hour more	+	1·2	1·0	·8	·6	·5	·4	·3	·2
			One hour less	−	1·5	1·3	1·1	·9	·7	·6	·4	·3
			One mile more	−	·6	·6	·5	·5	·5	·5	·4	·4
			Add (L − M)	×	·7	·8	1·0	1·0	1·1	1·2	1·3	1·4
			Standard march in miles 5RF		15	13·5	12	10·5	9	7·5	6	4·5

With echeloned camps, and gain C, take standard march as 5RF+C.

The correction for (L − M) is only to be used when L is greater than M.

EXAMPLE.—Road 20 ft.; F=·9; T=15 hours; march 20 miles, theoretical M=24·5 miles.

Column to march 13·5 miles in 12 hours ..	12·3
For 3 hours more, add 3×1·4	+4·2
Column to march 13·5 miles in 15 hours ..	16·5
For 11 miles more, deduct 11×·6	−6·6
Column to march 24·5 miles theoretical (or 20 miles actual) in 15 hours	9·9

54. PROBLEMS OF CONCENTRATION.

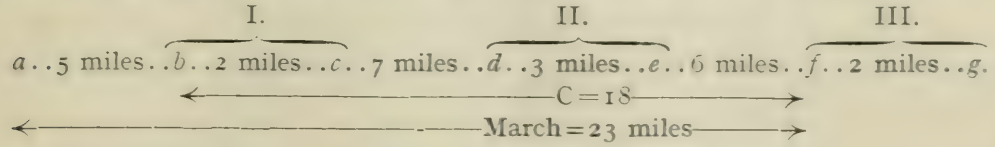
The use of the Capacity Table for the solution of such problems will be shown by an example.

EXAMPLE 12.—The road has a factor of ·9 and a width of 20 ft.

There are 12 hours daylight, and starlight nights.

The distribution of troops is shown on the accompanying sketch.

What strength of troops could be concentrated 5 miles ahead of the leading camp in 21 hours, the conditions being favourable?



NOTE.—There are 5 miles of troops at each camp.

The time available is $12+\frac{2}{3}9$, or 18 hours.

Take the case of camp *f*, which is 23 miles from *a*, the proposed place of concentration.

The actual march being 23, the theoretical march is 29·5 miles.

The standard march is 5RF+C, or 13·5+18, viz., 31·5 miles.

Column to march 31·5 miles in 12 hours ..	12·3
For 6 hours more, add 6×1·4	+8·4
Column to march 31·5 miles in 18 hours ..	20·7
For 2 miles less, add 2×·6	+1·2
Column to march 29·5 miles in 18 hours ..	21·9

Roughly 22 miles of troops could be concentrated at the required point in 21 hours.

By means of a "Concentration Diagram" constructed for this example it would appear that 23·7 miles of troops could be concentrated in the time.

55. CAPACITY TABLE FOR LENGTH OF MARCH OR TIME.

The procedure to find the length of march will be shown by an example.

EXAMPLE 13 (*see* Example 10, Section 50).—The road has a factor of ·9 and a width of 20 ft.

There are 12 hours daylight, and starlight nights.

The column of troops is 10 miles long, and echeloned along 4 miles of road. How far in front of its rearmost camp could it be concentrated in 24 hours, under favourable conditions?

Assume two lengths of march, 20 and 30 miles respectively.

For an actual march of 20, the theoretical march is 24·5 miles.

For an actual march of 30, the theoretical march is 42·5 miles.

The time available is $12+\frac{2}{3}12$, or 20 hours.

The standard march is 13·5+4, or 17·5 miles.

	M=24·5	M=42·5
Column to march 17·5 miles in 12 hours	12·3	12·3
For 8 hours more, add 8×1·4 ..	+11·2	+11·2
Column to march 17·5 miles in 20 hours	23·5	23·5
Correction for M	−4·2	−15·0
Column to march M in 20 hours ..	19·3	8·5

(1). When L=19·3, actual march=20

(2). When L= 8·5, actual march=30

Difference 10·8 10

So difference of 1 mile in L gives ·9 miles in M.

The actual column is 10 miles, or 1·5 miles more than (2), so the actual march is $30-(1{\cdot}5\times{\cdot}9)$, or 28·7 miles.

The concentration could be affected 28·7 miles in front of the rear-most camp. The calculated distance was 29 miles.

In problems of time, assume two times instead of two lengths of march, and then proceed as above.

56. FORCED MARCH THROUGH A DEFILE.

Although the distance may be short and a good night's rest be allowed, this operation often partakes of the nature of a forced march, as it is generally impracticable to allow proper rest-halts which would be advisable from the length of time the men are on foot. When the movement is carried out, moving day and night, the conditions must be considered unfavourable and the road factor reduced accordingly.

EXAMPLE 14.—The road through a defile, 5 miles long, has a road factor of ·5 and a width of 12 ft. There are 12 hours daylight, and starlight nights. How long would it take to pass 30 miles of troops, starting at 6 a.m. after a good night's rest ?

F must be taken ·4, to allow for the unfavourable conditions.

For width of road 12 ft., K=2, so KM=10, and $r={\cdot}53$.

Substituting in Formula 1 :—

$$T\times{\cdot}53-30+0=5, \text{ so } T=\frac{35}{{\cdot}53}=66 \text{ hours.}$$

The march would take 66 hours reckoned by daylight ; as 24 hours day and night are equivalent to 20 hours by day, 66 hours by day really mean 3 days and 6 hours.

The rear of the column would clear the defile at noon on the fourth day.

The time taken by any individual member of the column would vary from 6·6 hours by day, which is not excessive, to 10 hours by night which would be very trying at this slow pace. To allow even half-an-hour's halt half-way through the defile would necessitate numerous halts and would delay the passage by a further 10 to 12 hours. If however there were open ground midway, allowing of a portion of the column forming up, a halt could be given with advantage, as the march, as a whole, would only be delayed by the duration of one such halt.

57. CONTINUOUS MARCHING BY ALTERNATE BODIES OF TROOPS.

By this method continuous use is made of the road, one body advancing while the other halts, and *vice versâ*, day and night. From this it follows that the time allowed for marching and for halts must be equal, reckoned in hours of daylight. In this way the force is

relatively more concentrated than in ordinary marching, and a higher rate of advance can be maintained for several days in succession, without detriment to the power of concentration for battle.

If the road is wide enough to allow motor lorries to pass the column on the march, the supply service can be carried out after a fashion, but when the road is narrow the troops must depend on what they carry with them or can obtain from the country adjacent to the road. For the full success of this method it is thus essential that the country traversed should be populous and fertile, and that supplies of water should be obtainable at very frequent intervals on both sides of the road. Further, as the nature of the movement strictly limits the halts to fixed hours, it is impossible to go far afield in search of billets, and open billets or bivouacs must be largely resorted to.

As soon as the time allotted for marching has expired the whole marching column must at once and simultaneously clear the road, moving into the fields, or on a broad road to one side. It is thus, more or less, essential that the road should not be enclosed. Any forming up must be done after quitting the road, and, as this curtails the period of rest, should be by small units only.

From what has been said about supply it is evident that the troops should be accompanied by, at least, a part of their second-line transport, and as this must be interspersed in the column the loads of the leading units should be reduced to allow of the transport conforming to the rate of the troops. The necessary reduction may be calculated by the rough rule that a 10 per cent. reduction of net load gives 5 per cent. increase of marching rate.

Under favourable circumstances a force of three to six divisions can make use of a single road, and maintain a high rate of advance for several days in succession, without excessive hardship to the men and animals. But under unfavourable conditions the method is liable to all the drawbacks and hardships of forced marching.

The system is made clear in *Diagram* 4, p. 50, where a force of three divisions is shown marching by alternate half divisions, with $\frac{3}{4}$-mile distance between each, by which arrangement the rate of marching is that due to $7\frac{1}{2}$ miles of troops, which, on a road with a factor of ·9 and a width of 20 ft., is 2·4 miles an hour.

The right halves of the three divisions march from midnight to 7 a.m., halt till noon, again march till 5 p.m., and then halt to midnight.

The left halves of the three divisions halt from midnight to 7 a.m., march till noon, halt till 5 p.m., and then march till midnight.

At noon and midnight the divisions are complete. Between halts the march is $5 \times 2{\cdot}4$, or 12 miles, so the force covers 24 miles in the day.

Deducting one hour from the halt for forming up, obtaining water,

arranging open billets or bivouacs, etc., the leading half-divisions would have 4 hours' rest before noon, and 6 hours at night. Similarly the rear half-divisions would have 5½ hours after midnight, and 4 hours after noon. In the aggregate the period of rest appears ample, but from this must be deducted any time lost in obtaining water, or arranging billets, and further the period of rest is not continuous.

For these reasons the full rate of marching could not be maintained on successive days, and on the third day might fall to that obtained when the factor was reduced from ·9 to ·8. For the first three days we might expect marches of 24, 22·5, and 21 miles respectively.

This method of marching may be compared with that described in Section 45 as below :—

	Section 45. Ordinary Marches.	Section 57. Continuous Marching.
Length of march in one day, miles	17	24
Length of march in three days, miles	51	67½
Road space, three divisions, miles	29 to 48	24 to 36
Road space, four divisions, miles	45 to 64	32 to 45
Troops* concentrated in 24 hours, miles ..	30	30 to 40

* Assuming 10 miles of troops from each division.

It must, however, be noted that the leading troops, halting in what is little better than column of route, are not well situated for attack or defence, and thus, if this method of advance be adopted, the force must be covered during the movement by a stronger advanced guard than would be otherwise necessary, and one so organized that the mobility should not suffer.

Under exceptional circumstances this method may be of great value in bringing off a coup, but it depends for success on too many favourable conditions to be suitable for ordinary use.

58. Continuous Marching, Double Marches.

This is another alternative by which the road is used day and night, each small body, such as a brigade, marching a specified distance, halting a specified time off the road, and then marching again to another specified halting place. Each brigade marches off in succession, and halts in succession, without affecting the movement of those in rear.

By this system the halting places can be chosen where there are facilities for water, food and rest, so that it can be adapted to more ordinary conditions, and further the duration of halts need not, as in the last section, be equal to the time allotted for the march. The system is thus more flexible and of more practical utility. The *sine quâ non* is that each halting place must have sufficient room for all troops which arrive during the period of the halt.

The organization at each halting place must be carefully worked out by the staff so that incoming units move to their positions without interfering with those which are moving off after their rest, and further that neither of these movements are checked by men or animals moving to or from the water supply or in search of food or fuel.

One important effect of this system is that no marching column is longer than the distance between halting places, so that a relatively high rate of marching is possible, even if a larger force is making use of a single road. Further, as a considerable concentration takes place at each halt, the movement is not so vulnerable as that described in the last section, and specially strong advanced guards are unnecessary.

If the road is a broad one motor lorries can bring up supplies, and their distribution is facilitated by the halting places being fixed. Otherwise the troops must depend on what they carry with them or can obtain from the country. Billeting is difficult and a larger use must be made of bivouacs.

For these reasons each brigade should be accompanied by a portion, at all events, of its second-line transport, the loads of which should be reduced to allow its maintaining the pace of the troops.

By this system a large force can be kept relatively concentrated, while it is able to maintain a rapid advance for several days in succession.

The general method is shown in *Diagram* 5, p. 50, for a force of three divisions, each shown as divided into seven smaller bodies for convenience of illustration. If the road has a factor of ·9, and a width of 20 ft., the halting places might be 11 miles apart, and the force could advance 22 miles in 24 hours. For M=11, we get $r=2{\cdot}2$. Assuming a general rate of 2·2 miles per hour, the time table for the three divisions would be as follows :—

		1st Division.		2nd Division.		3rd Division.	
		Van.	Rear.	Van.	Rear.	Van.	Rear.
March from	..	6 a.m.	1 p.m.	1 p.m.	9 p.m.	9 p.m.	7 a.m.
to	..	11 a.m.*	6 p.m.	6 p.m.	4.30 a.m.	4.30 a.m.	12 noon
Halt from	..	11 a.m.	6 p.m.	6 p.m.	4.30 a.m.	4.30 a.m.	12 noon
to	..	3 p.m.	10 p.m.	10 p.m.	8.30 a.m.	8.30 a.m.	4 p.m.
March from	..	3 p.m.	10 p.m.	10 p.m.	8.30 a.m.	8.30 a.m.	4 p.m.
to	..	9 p.m.†	5.30 a.m.	5.30 a.m.	1.30 p.m.	1.30 p.m.	10.30 p.m.
Halt from	..	9 p.m.	5.30 a.m.	5.30 a.m.	1.30 p.m.	1.30 p.m.	10.30 p.m.
to	..	6 a.m.	1 p.m.	1 p.m.	9 p.m.	9 p.m.	7 a.m.

* Actually a little after 10 a.m.

† Actually about 7.30 p.m.

It will be observed that the long halts for the rear of the 1st Division, the whole of the 2nd Division, and the van of the 3rd Division, are largely by daylight, but this cannot be avoided if the leading division is to march off at 6 a.m.

It is evident from the time table that, in addition to the inter-

mediate halt of 4 hours, the rear of the 1st Division has a long halt of $7\frac{1}{2}$ hours, of the 2nd Division $7\frac{1}{2}$ hours, and of the 3rd Division $8\frac{1}{2}$ hours, so the force as a whole would have from 5 to 6 hours' rest, exclusive of the intermediate halt. As the march of 22 miles is only $8{\cdot}2 \times RF$ miles, or a little above the normal, the force should be able to accomplish its 22 miles daily, for four or five days in succession, provided the weather was favourable and supplies sufficient.

COMPARISON WITH THE ORDINARY MARCHING SHOWN IN SECTION 45.

	Section 45. Ordinary Marches.	Section 58. Double Marches.
Length of march in one day, miles	17	22
Length of march in three days, miles	51	66
Road space, three divisions, miles	29 to 48	17 to 22
Road space, four divisions, miles	45 to 64	26 to 33
Troops* concentrated in 24 hours, miles	30	30 to 40

* Assuming 10 miles of troops from each division.

The system has the further advantage that the halting places need not be equal distances apart, but may be adapted to the locality, though most satisfactory results are obtained when they are nearly so.

Ordinary marching can readily be converted into the system of double marching, which is a further advantage.

59. CONCLUSION.

There is nothing novel in the principles elucidated in the foregoing sections.

The data necessary for the calculations involved would in the ordinary course be required by any commander or staff officer planning an advance, where accurate combination is an essential element of success.

What is new is the method of determining the rate of march under conditions which differ from the normal, with a considerable degree of certainty and accuracy.

The method may appear somewhat artificial and theoretical, but as it has been successfully applied to the solution of numerous marches, ranging from those on first-class European roads, under favourable conditions, to others on execrable mule tracks in the mountains of Thibet, under unfavourable conditions, its value would appear to be practically demonstrated, while it deals with a subject almost untouched in our existing text-books.

As "the strength of an army, like the power in mechanics, is estimated by multiplying the mass by the rapidity,"* everything is helpful which assists a commander to make full use of the marching power of his men and animals, consistent with their continued

* Maxims of Napoleon.

endurance. It is hoped that these Notes will be of assistance in this respect, and also in the timing of marches, which is so essential in strategical combinations.

DIAGRAM 4.

Continuous Marching by Alternate Bodies (Section 57).

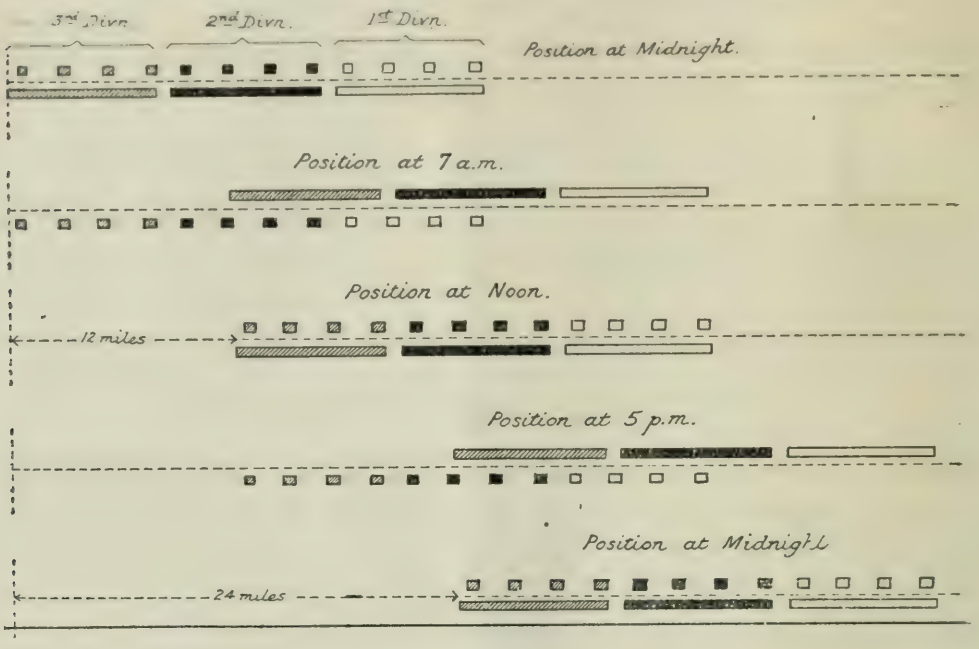
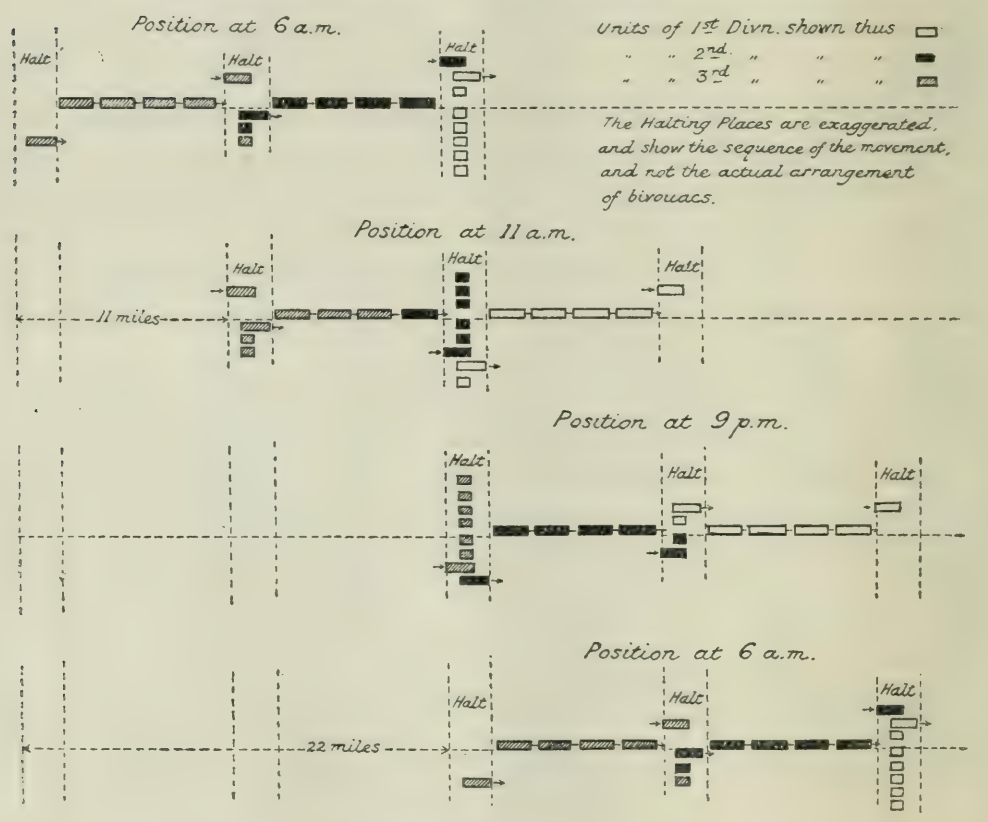


DIAGRAM 5.

Continuous Marching, Double Marches (Section 58).



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* Sections so marked were practically tested on the Thibet Expedition of 1903–04.

60. GENERAL CONSIDERATIONS.

It is sometimes remarked that transport on communications appears less efficient than when marching with a force. The marching power of the animals, and also their loads, are the same in both cases, but the conditions are different.

Transport with troops has generally a period of marching followed by a period of comparative inaction while a fresh advance is being organized, while on the line of communications it is worked day after day without intermission.

Further, with troops, there are generally plenty of men available to assist in the operations of loading and unloading, while on communications this, as well as other essential work, is thrown almost entirely on the transport and supply establishments, and the time so consumed lessens the number of hours available for actual marching.

It is also difficult on communications, more especially when hired, or extemporized, transport is used to any great extent, to maintain the discipline of transport drivers and establishment at the same standard as with troops, and the output of work consequently suffers.

The roads also from constant usage deteriorate rapidly, and though repair gangs may be detailed to keep them in order, it is difficult to do so without causing some interference with traffic.

All the above considerations tend to reduce the apparent capacity of a given road for line-of-communication work, and are, in part, unavoidable.

The capacity may be further reduced by certain avoidable causes, such as a system of convoy work which is not suited to the conditions; by lack of proper organization in the subsidiary, but essential, duties of issuing loads, loading, and unloading, stacking, checking, or transferring loads; by overwork due to insufficient rest, spare animals, or allowance for casualties; by badly-planned stages, posts or depôts; and by various other considerations which will suggest themselves to every supply officer.

The successful working of communications calls for organization, discipline, method and forethought, of a high order, which can only be secured by a thorough knowledge of the conditions that militate against efficiency.

61. TRANSPORT EMPLOYED ON COMMUNICATION.

A great variety of transport may be employed on communications. Some of the commoner forms are given in Table IX. In this table are shown:—The clear width of road required; the road space required by each vehicle or pack animal; the number per mile of road; the maximum useful gradient above which the efficiency of that form of transport falls off; the limiting gradient a short length of which can be surmounted with difficulty; the regulation load;

the rate in miles per hour on a standard road where F=1; and the food required by each animal.

TABLE IX.—TRANSPORT.

	Minimum Width of Road.	Road Space for Each.	Number per Mile.	Gradient.		Regulation Load	Rate on Standard Road when Fed.	Food.	
								Grain.	Forage.
	Ft.	Yds.	No.	Maximum Useful.	Maximum.	lbs.	Miles per hour.	lbs.	lbs.
Wheeled.									
G.S. wagon	8	15	120	1/15	1/10	3100	2¾	12	12*
Forage carts	8	10	180	1/15	1/10	1540	2¾	12	12*
Bullock carts (with 2 bullocks)	8	7	250	1/15	1/10	960§	2	6	14
Each extra pair of bullocks ..	—	3	70	—	—	800	—	—	—
Mule carts (2 mules)	8	7	250	1/15	1/10	800	2¾	6	15
Each extra pair of mules ..	—	3	70	—	—	700	—	—	—
Pony cart (Ekka)	7	6	300	1/15	1/10	400‡	2¾	6	15
,, ,, ...	7	6	300	1/15	1/10	320	3	6	15
Hand cart (4 men)	7	6	300	1/15	1/10	400	2	—	—
Pack.									
Bullocks	7	6†	300	1/8	1/5	160	2½	4	14
Mules (single file)	6	4	450	1/8	1/3	160	3	6	15
,, (2 abreast)	12	2½	700	1/8	1/3	160	3	6	15
Ponies (single file)	6	5†	350	1/8	1/3	160	3	6	15
Camels (Indian)	9	5	350	1/10	1/8	400	2¼	6	16
,, (Mongolian)	9	5	350	1/10	1/8	480	2¼	6	16
,, (African)	9	5	350	1/10	1/8	300	2¼	6	16
Coolies (Indian) from plains ..	4	3	600	1/8	1/5	40	2	—	—
,, ,, ,, hills ..	4	3	600	1/6	1/3	80	2	—	—
Donkeys	5	4†	450	1/10	1/8	100	2	4	10
Porters (African)	4	3	600	1/6	1/3	65	2	—	—
Mechanical.									
Motor lorries	9	20	90	1/10	1/8	5000	10	—	—

* 1 lb. English hay = 1½ lbs. Bhoosa = 2½ lbs. green grass.

† Pack bullocks, ponies and donkeys bunch together on the march and interfere with each other, thus causing relative loss of distance.

‡ The official load in India is 480 lbs., but this is too great except in favourable circumstances.

§ Load for bullock cart on hilly roads is 800 lbs.

62. SYSTEMS OF CONVOYS.

Convoys may be worked on one of four systems :—

Through Convoys.

Staging—

(*a*). By Full Stages.

(*b*). By Meeting.

(*c*). By Short Stages.

63. THROUGH CONVOYS.

"This system consists in the same animals and vehicles being employed from the start of the convoy until its arrival at its destination," and is generally adopted to link up a force with its advanced depôt.

The convoy takes with it an escort if required, tents if any, its baggage, and food for men and animals for both the outward and homeward journeys unless these are procurable locally. The net power available for supplies for the force is thus reduced, but the convoy has greater latitude in its movements and generally speaking requires, relatively fewer men for its protection as there are no posts to garrison.

In calculating the net power of a through convoy, which has 5 per cent. spare, and works x marches ahead of the advanced depôt and back carrying its own supplies in whole or in part, the simplest procedure is as follows :—

Total number of vehicles (or pack animals)	..	105
Number of loaded vehicles	..	100
Deductions :—		
Corps equipment for 105 vehicles ..	say	3
Baggage, kits, etc., for 105 vehicles ..	,,	2
Food for $2x - 1$ days for animals and men of establishment for 105 vehicles	say	8
Total deductions	..	13
Net number of vehicles, carrying stores for front	..	87

Then for every vehicle load of stores to be delivered at the front we require $\frac{105}{87}$ or 1·21 vehicles in the convoy, exclusive of the escort.

The number of vehicles required by the escort, including baggage, food, etc., can be calculated, and for every vehicle so required, 1·21 vehicles must be added to the convoy.

64. FULL STAGES.

The road is divided in convenient stages, "the same section of the transport working over the same ground, proceeding laden and returning empty," or *vice versâ*.

If the road is broad, a double lot of transport works on each stage, so that while one is proceeding laden the other is returning empty, but on narrow roads the convoy goes forward laden one day, and returns empty the next.

As however the convoy is in either case away from its own post every alternate night, it must carry some kit and one day's supply for itself and should be furnished with 3 per cent. of spare.

This system gives the largest capacity when there is no suitable place for an intermediate post, or when it is necessary to economize line-of-communication troops, and when the stage need not be worked to its full capacity it offers the balance of advantages, if there is no suitable place for meeting and transferring loads midway.

65. MEETING SYSTEM.

Posts are established as in the last system a day's march apart. For each stage two lots of transport are provided, one located at each end of the stage. They work to meet each other midway between the two posts, one loaded and the other empty. On meeting, loads, or vehicles, are transferred and each lot returns to spend the night at its own post.

With Government vehicles it is not necessary to transfer loads, but the loaded vehicle and its equipment may be handed over; this cannot, however, be done with hired transport.

A certain amount of time is lost in the transfer, so that the capacity of a stage under this system is inferior to full stages, but the system makes the work easier for both men and animals, as they return each night to the same resting place. For the same reason they do not have to carry kit or food, and the spare may be reduced to 2 per cent. The system is not suitable for camel transport owing to the great loss of time in transferring loads.

The meeting place may be on the road itself, the convoys halting in column of route, or on any convenient open space off the road where they can form. In the former case the road should be four times the width required by a single vehicle, or pack animal, for a length rather longer than a single convoy. In the latter case the open space should have a total area at least sufficient for the amount of transport which can arrive in the time necessary for the transfer. It is desirable to allow 150 square yards for each G.S. wagon, 100 square yards for each pair-horse vehicle, 50 square yards for each bullock or mule cart, and 25 square yards for each pack animal.

The arrangements for meeting require great care to prevent confusion and loss of time. The empty convoy, marching faster and arriving first, should be formed up before the arrival of the laden one. If on an open space this can be done in a number of parallel columns, with at least 4 yards clear interval for pack animals, 6 yards clear for carts, and 8 yards clear for G.S. wagons. The incoming laden convoy files into the intervals and transfers vehicles or loads. After the transfer it is important, to avoid the necessity of columns crossing each other, that each column should leave the ground by the same route by which it entered, countermarching if the intervals are restricted.

If the road is not broad enough for two convoys to pass, it must be widened on each side of the meeting place for a distance equal to the length of the convoy less that portion of it which can move on to the ground in the time taken in the transfer. If this cannot be done the capacity of the stage is reduced to that of a narrow road.

66. SHORT STAGES.

In this system each convoy proceeds laden and returns empty the same day, the posts being located roughly half a day's march apart, or at what would be transferring places under the meeting system. It possesses all the advantages of the latter, with the further gain that the strain on men and animals is even less, loads are delivered at the next post shortly after noon, when the checking, sorting, etc., can be done by daylight, thus easing the work of the supply establishment, and making for increased efficiency. The short stage system admits of the road being worked to its maximum capacity. It has the disadvantage, however, that loads take longer *en route* and that twice as many posts must be established, guarded and fed. On a long line of communications the additional transport due to the extra posts and garrisons may exceed the gain in capacity, in which case full stages should be employed.

On the limiting stages of a line the short stage system is very advantageous as it alone allows of the maximum capacity being developed.

67. ABNORMALLY LONG STAGES.

The position of staging posts depends on considerations of water, space, and defensibility, and cannot in practice be located as purely transport requirements might indicate. It thus is often necessary to use longer stages. The disadvantage of these may be minimized by using a faster form of transport. If this expedient cannot be adopted we must work longer hours, and correspondingly increase the percentage of spare at the post to allow of adequate rest after overwork. Fifty-five per cent. of spare would allow of one day's rest after two days' marching.

68. ABNORMALLY SHORT STAGE.

When a difficult ford, or weak bridge, occurs in a stage, the capacity is much reduced as the usual distances between vehicles or pack animals cannot be maintained with safety. In such cases it is advisable to reduce the length of the stage so that the capacity of the line as a whole may not be diminished. Under such conditions it may be even necessary to make the obstacle a stage in itself, by locating a post at each end or as near as the ground admits.

69. THE CAPACITY OF A STAGE.

The capacity of any stage may be expressed as the maximum number of vehicles or pack animals which can be employed on it daily, without waste of power. It thus depends on the time available for marching, the length of the stage, and the nature of the road, and of course varies with the class of transport employed.

The power of the line of communications is determined by the capacity of its limiting stage, which is not necessarily the worst stage, as will be seen from Section 95.

If a line of communication be laid out without any regard to capacity of the individual stages there is certain to be a waste of power. This will become evident in time from the accumulation of stores at certain posts and may be rectified gradually by adjustments. But it is evident that by this trial and error method much valuable time and power will be uselessly expended. If, on the other hand, the capacity of the individual stages be gauged with approximate accuracy in the first instance, the line can be laid out to gain efficiency from the start, and to reduce subsequent alterations to a minimum thus saving much trouble and loss of power. The weak stages become apparent at once, and measures may be taken betimes to improve these either by transport or engineering expedients.

The limitations imposed by the capacity of a stage may be illustrated by an actual case in the Thibet Expedition of 1903–04. A bad stage was being worked by transport, the power of which was equivalent to 600 loads daily, which proved insufficient to prevent an accumulation of stores. To get rid of this, additional transport with a power of 400 loads daily was allotted to the stage, thus bringing its daily power up to 1,000 loads. With this increased power the stage could only forward, on the average, 650 loads a day, and consequently transport equivalent to a power of 350 loads daily was being wasted, on an attempt to work the stage beyond its capacity. In this case the difficulty was surmounted by using an alternative track over a neighbouring pass.

70. WORKING HOURS.

The number of working hours is limited largely by the necessity of maintaining the strength and efficiency of the men and animals during the long, monotonous and sustained effort inseparable from work on communications.

Exclusive of any time required for morning or evening meals, etc., it is not advisable to rely on much more than 12 working hours daily, for the convoy as a whole.

Should any of these working hours, other than those devoted to marching, occur at night, they must be reduced to their equivalent by daylight, or in the proportion of 3 to 2.

Should any portion of the march take place by night, the equivalent of each such hour should be taken as five-sixths, two-thirds, or one-half, on moonlight, starlight, or dark cloudy nights respectively.

In the working hours are included the operations of loading, unloading, transferring, and stacking the loads, together with other miscellaneous duties, as well as balance of time available for actual marching.

71. WORK OTHER THAN MARCHING.

The arrangements for issuing loads should, if possible, be carried out overnight by establishment other than the transport drivers, and the final check at the end of the day concerns the supply establishment.

But the other duties fall, in large measure, on the *personnel* of the transport.

In the annexed tabular statement is given a detail of these latter duties and the approximate time required. But though this is based, more or less, on actual experience, it must not be considered exact, as no portion of the work on communications is more dependent on the individual ability of the officer, or on the degree of organization, method and discipline attained. It is given mainly to show how the balance of time available for marching is arrived at, on which the Capacity Tables are calculated.

If by ability and organization it is possible to reduce the time required for loading, etc., that available for marching and the capacity of the stage will be increased. While if circumstances, or the conditions of the individual case, necessitate more time being allotted to the above duties, the balance of time available for marching is reduced, and consequently the capacity of the stage diminished.

TIME ALLOTTED FOR LOADING, ETC. (IN HOURS).

	Motor Lorries.	G.S. Waggons.	Carts.	Camels.	Pack Mules.	Porters.
Through Convoys.						
Loading (first day only)	2	1	1	2	1	¾
Unloading (last day only)	1	½	½	1	½	¼
Stacking (last day only)	1	½	½	1	½	½
Miscellaneous	3	2	2	1	1	1½
Staging (Full Stages, or Short Stages).						
Loading	2	1*	1*	2	1	¾
Unloading	1	½*	½*	1	½	¼
Stacking	1	½*	½*	1	½	½
Miscellaneous	3	2	2	2	2	1½
* If the vehicles are transferred allow 1 hour in lieu of these.						
Meeting.						
Loading	—	1	1	2	1	¾
Transferring	—	1	1	3	2	1
Unloading	—	½	½	1	½	¼
Stacking	—	½	½	1	½	½
Miscellaneous	—	2	2	2	2	1½
If the loads are transferred add half an hour.						

Issuing.—The arrangements for this should be carried out overnight. If this cannot be done an additional hour should be allowed. With badly planned or restricted storeyards deficient in exits this allowance may be increased to two hours.

72. TIME AVAILABLE FOR MARCHING.

This is the difference between the total number of working hours considered admissible and the time taken on other duties such as loading, etc., both reduced to their equivalent in hours of daylight.

In the annexed tabular statement the time shown as available for marching is the difference between the 12 hours allowed in Section 70, and the time required for loading, etc., given in Section 71.

The number of hours on which the Capacity Tables are based are shown in bold figures.

TIME AVAILABLE FOR MARCHING.

	Motor Lorries.	G.S. Waggons.	Carts.	Camels.	Pack Mules.	Porters.
Through Convoys.						
First, or last, stage	7	9	9	7	9	9
Intermediate stages	9	10	10	7	9	9
Staging (Full Stages, or Short Stages).						
Vehicles going through :—						
First, or last, stage	**7**	**8**	**8**	—	—	—
Intermediate stages	8	9	9	—	—	—
Reloading daily	5	**8**	**8**	6	8	9
Meeting.						
Vehicles going through :—						
First, or last, stage	—	8	8	—	—	—
Intermediate stages	—	9	9	—	—	—
Transferring vehicles at mid stage only	—	**7**	**7**	—	—	—
Transferring loads	—	$6\frac{1}{2}$	$6\frac{1}{2}$	**3**	**6**	**8**

73. VALUE OF ROAD FACTOR.

The road factor was dealt with in Section 3 of Part I. of these Notes, but as it affects the capacity of stages Table I. is reproduced below, to render Part II. more complete in itself.

The value of the road factor, or F, can be found from the table by inspection, and corrected for the conditions, for which see foot of table.

I.—TABLE OF ROAD FACTORS.

Gradient.	Surface. Good.	Indifferent.	Bad.
PACK ANIMALS (deduced from practice).			
Gradient, 1 in 25, or less	1	·9	·8
,, 1 in 20	·9	·8	·7
,, 1 in 15	·8	·7	·6
,, 1 in 10	·7	·6	·5
,, 1 in 8	·6	·5	·4
VEHICLES (deduced from practice).			
Metalled Roads.			
Gradient, 1 in 25, or less	1	·85	·7
,, 1 in 20	·9	·75	·6
,, 1 in 15	·8	·65	·5
,, 1 in 10	·7	·55	·4
Unmetalled Roads.			
Gradient, 1 in 25, or less	1	·8	·6
,, 1 in 20	·9	·7	·5
,, 1 in 15	·8	·6	·4
,, 1 in 10	·7	·5	·3
MECHANICAL TRANSPORT (estimated).			
Gradient, 1 in 25, or less	1	·7	·5 to ·4
,, 1 in 20	·85	·65	·45 to ·35
,, 1 in 15	·7	·6	·4 to ·3
,, 1 in 10	·55	·45	·3 to ·25

For unfavourable conditions deduct ·1.
For very unfavourable conditions deduct ·2.
For unladen transport add ·2.

As a guide to the effect of *Surfaces* the following may be given :—

Indifferent.—Indifferently metalled ; very dusty ; rather cut up ; greasy ; muddy ; rough ; sandy ; stony.

Bad.—Badly metalled ; 4 to 6 in. of mud ; deep sand ; loose shingle ; very slippery ; 9 in. of snow ; very rough ; very stony.

As a guide to the classification of *Conditions* the following may be given :—

Unfavourable.—Rainy ; stormy ; hot and sultry ; after forced march ; after a bad bivouac ; after insufficient food or rest ; men and animals poorly trained ; men and animals in poor condition.

Very Unfavourable.—A combination of unfavourable conditions ; marching against a strong head wind ; making a third forced march in succession ; temperature 75° Fahr. (If the temperature is 90 degrees deduct ·3)

Where sections of a stage differ materially as to road factor, the mean value must be calculated, and will be found to be somewhat less than the arithmetical mean.

For exact determination divide the length of each section by its road factor, and the sum of the quotients so found by the total length of stage.

The road factor may also be deduced by the following simple rules, which can easily be committed to memory.

The standard road, for which the factor is unity, is in all cases assumed to have a gradient of 1 in 25 or less, and a good surface, and the conditions are considered favourable.

Proceed as follows :—

1. Find the factor for *Gradient* only, assuming the surface good and the conditions favourable.
2. Make any deduction necessary for *Surface.*
3. Make any deduction necessary for *Conditions.*

TROOPS AND TRANSPORT, OTHER THAN MECHANICAL.

1. *Gradient* on good surface, under favourable conditions :—

1 in 25 (or less)	F=1
1 in 20	F=·9
1 in 15	F=·8
1 in 10	F=·7
1 in 8	F=·6
1 in 6	F=·5

It will be noted the decrease is ·1 for each successive gradient.

2. *Deduction for Surface :—*

(*a*). For troops, first-line transport, and pack transport :—
Surface indifferent, deduct ·1.
Surface bad, deduct ·2.

(*b*). For wheeled transport of second line :—
For metalled roads, use 1½ times the deduction in (*a*).
For unmetalled roads, use twice the deduction in (*a*).

3. *Deduction for Conditions :—*

Unfavourable conditions, deduction ·1.
Very unfavourable conditions, deductions ·2.

MECHANICAL TRANSPORT.

1. *Gradient* on good surface, under favourable conditions :—

1 in 25 (or less)	1
1 in 20	·85
1 in 15	·7
1 in 10	·55

It will be noted the decrease is ·15 for each successive gradient.

2. *Deduction for Surface :—*

Surface indifferent, deduction from ·3 to ·1.
Surface bad, deduction from ·5 to ·2.

The better the gradient the greater the deduction.

3. *Deduction for Conditions :—*

Unfavourable, deduction ·1.
Very unfavourable, deduction ·2.

74. AVERAGE WIDTH OF ROAD.

The "Minimum" and "Useful Maximum" width of road for different classes of transport are given below in tabular form. The useful maximum, viz., twice the minimum, is that beyond which no practical advantage is gained from extra width of road, as long as the transport remains in single file.

Class of Transport.	Minimum. Feet.	Useful Maximum. Feet.
Motor lorries, Camels	9	18
G.S. wagons, Pair-horse carts, Mule carts, Bullock carts	8	16
Ekkas, Pack bullocks	7	14
Pack mules or ponies	6	12
Donkeys	5	10
Porters	4	8

When the road is not enclosed we may assume the width to be increased by 50 per cent., provided that the useful maximum is not exceeded.

To find the average width of the road for determining capacity, assume the actual width of any unenclosed portion increased by 50 per cent., discard in all cases any width in excess of the useful maximum, and find the arithmetical mean of the widths so corrected.

For instance, assume that a road has a width of 10 ft. for half the stage, and is enclosed (by walls, ditches or fences which prevent the transport, even temporarily, moving off the road in case of a block), while for the remaining half the road has a width of 12 ft. and is not enclosed. The latter portion is equivalent to an enclosed road 18 ft. wide, only 16 ft. of which is counted, as the useful maximum for carts is 16 ft. The average width for purposes of capacity is accordingly the mean between 10 and 16, or 13 ft.

If the road is so broad that the transport can move two or more abreast, the useful maximum is that obtained from the table multiplied by the number abreast.

75. TRANSPORT MOVING TWO OR MORE ABREAST.

In such cases divide the average width of road by the number abreast to find the mean width available for each vehicle, or pack animal, in single file.

The capacity of the stage for single file can then be obtained and multiplied by the coefficient given below to find the full capacity with transport marching abreast.

With 2-abreast*	multiplier $1\frac{2}{3}$
With 3-abreast	multiplier 2
With 4-abreast	multiplier $2\frac{1}{2}$
With 5-abreast	multiplier $2\frac{3}{4}$
With 6-abreast	multiplier 3

76. DESCRIPTION OF TABLE FOR CAPACITY OF STAGES.

A separate table is given for each class of transport.

In the table will be found, under different values of F (the road factor) and opposite the width of road, the approximate number of vehicles, or pack animals, which can usefully be employed in single file on the length of stage, and in the marching hours stated on the table, for each of three systems of working stages.

Immediately below this is shown the correction for each hour by which the time available for marching exceeds, or falls short, of that stated in the table, to be added when more time is available, and to be deducted when less time is available.

Below the above correction, is given a similar one for each mile by which the stage falls short of, or exceeds, the length of march stated in the table, to be added if the march be less, and to be

* When pack mules are two-abreast, and the number per mile is taken from Table IX., this multiplier is not required.

deducted if the march is longer than that on which the table is calculated. Only three widths of road are shown; the widest in each case is the "Useful Maximum" and admits of transport passing on the march.

The narrowest is the "Minimum," on which transport cannot pass on the march. An intermediate width is also given. If the actual road does not approximate to any one of these, intermediate values may be interpolated.

77. USE OF TABLES FOR CAPACITY OF STAGES.

The tables are designed to allow of a rapid determination of the approximate capacity of a stage, the number of hours available for marching and the length of stage being given. But they may also be used to find the length of stage, or the number of marching hours necessary to secure any required capacity. These processes will be illustrated by examples.

We will assume that the transport is pack mules, that the full stage system is adopted, and that the road has a factor of ·8, and a width of 9 ft.

(a). To find the Capacity.

The stage is 12 miles long, and the time available for marching is 7 hours.

Capacity for 8 hours, and 10 miles	1830
For 1 hour less, deduct 1×454	−454
Capacity for 7 hours, and 10 miles	1376
For 2 miles more, deduct 2×170	−340
Capacity for 7 hours, and 12 miles	1036

The capacity is 1,036 mules every second day.

(b). To find the Length of Stage.

The requirements are 518 mules daily, and the time available for marching is 7 hours.

As the road is 9 ft. wide, a loaded convoy can only pass every second day, and so must consist of 1,036 mules to satisfy the requirements.

Capacity for 8 hours, and 10 miles	1830
For 1 hour less, deduct 1×454	−454
Capacity for 7 hours, and 10 miles	1376
The required capacity is	1036
Difference	340

The correction for 1 mile being 170, the stage may be lengthened by $\frac{340}{170}$, or 2 miles.

(c). *To find the Marching Time Required.*

The requirements are 1,036 mules every second day, and the length of stage is 12 miles.

Capacity for 8 hours, and 10 miles	..	..	1830
For 2 miles more, deduct 2×170	..	..	−340
Capacity for 8 hours, and 12 miles	..	..	1490
The required capacity is	..	..	1036
Difference ..	..	..	454

As the correction for 1 hour is 454, the time required will be less than 8 hours by $\frac{454}{454}$, or 1 hour.

The marching time required is 7 hours.

TABLE XI.—CAPACITY OF STAGES.

12 Working Hours by Daylight.

MOTOR LORRIES.

Full Stages.

Marching 40 miles. Marching 7 hours.

	F=1	F=·9	F=·8	F=·7	F=·6	F=·5	F=·4	
Road 18 ft. ..	1215	900	600	324	70	−166	−385	Daily.
One hour more	+ 315	270	232	198	172	149	128	,,
One mile less ..	− 41	39	37	36	35	33	32	,,
Road 13½ ft. ..	931	668	436	232	48	−115	−264	Every second day.
One hour more	+ 206	173	149	129	113	99	88	,, ,, ,,
One mile less ..	− 31	29	27	25	24	23	22	,, ,, ,,
Road 9 ft. ..	747	530	340	180	36	−89	−200	Every second day.
One hour more	+ 147	129	112	95	85	74	66	,, ,, ,,
One mile less ..	− 25	23	21	20	19	18	17	,, ,, ,,

Short Stages.

Marching 40 miles (20 going, and 20 returning). Marching 7 hours.

	F=1	F=·9	F=·8	F=·7	F=·6	F=·5	F=·4	
Road 18 ft. ..	1380	1055	735	440	167	−80	−310	Daily.
One hour more	+ 320	275	235	200	174	150	129	,,
One mile less ..	− 42	40	38	37	35	34	33	,,
Road 13½ ft. ..	787	588	408	243	92	−40	−170	Daily.
One hour more	− 198	137	117	102	89	75	66	,,
One mile less ..	+ 23	22	21	20	19	18	17	,,
Road 9 ft. ..	661	490	336	197	75	−36	−135	Daily.
One hour more	− 125	106	91	80	68	59	52	,,
One mile less ..	− 19	18	17	16	15	14	13	,,

TABLE XI. – *Continued.*

G.S. WAGONS (Single File).

Full Stages.

Marching 10 miles. Marching 8 hours.

		F =1	F =·9	F =·8	F =·7	F =·6	F =·5	F =·4	
Road 16 ft. ..		790	632	480	330	189	56	– 62	Daily.
One hour more	+	192	159	139	117	97	77	57	,,
One mile less ..	+	66	65	64	61	59	56	53	,,
Road 12 ft. ..		673	529	398	268	150	43	– 47	Every second day.
One hour more	+	154	133	116	96	78	60	43	,, ,, ,,
One mile less ..	+	56	54	52	49	47	43	38	,, ,, ,,
Road 8 ft. ..		584	455	337	224	124	35	– 37	Every second day.
One hour more	+	134	115	97	80	64	48	34	,, ,, ,,
One mile less ..	+	49	47	44	42	38	35	31	,, ,, ,,

Meeting.

Marching 10 miles (meeting at 5 miles). Marching 7 hours.

Road, 16 ft. ..		624	486	350	220	95	– 28	– 120	Daily.
One hour more	+	185	163	143	121	101	80	60	,,
One mile less ..	+	67	66	65	64	61	59	54	,,
Road, 12 ft. ..		362	283	203	127	55	– 13	– 78	Daily.
One hour more	+	108	96	82	71	59	48	37	,,
One mile less ..	+	40	38	37	36	35	34	33	,,
Road, 8 ft. ..		333	257	182	114	49	– 12	– 68	Daily.
One hour more	+	99	86	74	62	52	42	32	,,
One mile less ..	+	36	35	33	32	31	30	29	,,

Short Stages.

Marching 10 miles (5 going and 5 returning). Marching 8 hours.

Road, 16 ft. ..		870	696	535	377	228	86	– 39	Daily.
One hour more	+	203	168	146	124	102	80	60	,,
One mile less ..	+	70	68	67	65	61	59	55	,,
Road, 12 ft. ..		492	404	304	210	121	37	– 43	Daily.
One hour more	+	115	102	88	74	62	50	39	,,
One mile less ..	+	42	41	40	39	38	37	36	,,
Road, 8 ft. ..		455	365	271	185	106	32	– 37	Daily.
One hour more	+	104	91	78	66	54	43	34	,,
One mile less ..	+	38	37	35	34	33	32	31	,,

TABLE XI.—*Continued.*

PAIR-HORSE CARTS (Single File).

Full Stages.

Marching 10 miles. Marching 8 hours.

		F = 1	F = ·9	F = ·8	F = ·7	F = ·6	F = ·5	F = ·4	
Road, 16 ft. ..		1186	950	720	495	285	85	− 94	Daily.
One hour more	+	290	240	209	176	146	115	86	,,
One mile less ..	+	99	97	95	92	88	85	79	,,
Road, 12 ft. ..		1010	794	598	401	225	65	− 70	Every second day.
One hour more	+	230	200	173	144	117	90	65	,, ,, ,,
One mile less ..	+	85	81	77	74	70	65	58	,, ,, ,,
Road, 8 ft. ..		877	682	506	337	185	52	− 56	Every second day.
One hour more	+	202	173	146	121	95	72	50	,, ,, ,,
One mile less ..	+	74	70	67	63	58	52	47	,, ,, ,,

Meeting.

Marching 10 miles (meeting at 5 miles). Marching 7 hours.

Road, 16 ft. ..		936	729	526	330	142	− 41	− 180	Daily.
One hour more	+	278	245	214	182	151	121	90	,,
One mile less ..	+	101	99	97	95	92	88	81	,,
Road, 12 ft. ..		544	435	304	191	83	− 20	− 117	Daily.
One hour more	+	102	144	122	106	88	72	56	,,
One mile less ..	+	60	58	56	55	54	52	50	,,
Road, 8 ft. ..		501	385	274	171	74	− 18	− 103	Daily.
One hour more	+	150	130	112	94	80	63	49	,,
One mile less ..	+	54	52	50	49	47	45	43	,,

Short Stages.

Marching 10 miles (5 going and 5 returning). Marching 8 hours.

Road, 16 ft. ..		1305	1044	803	565	342	130	− 60	Daily.
One hour more	+	304	252	220	186	153	121	90	,,
One mile less ..	+	104	103	101	98	92	88	83	,,
Road, 12 ft. ..		738	607	455	315	182	56	− 66	Daily.
One hour more	+	173	153	131	112	94	76	60	,,
One mile less ..	+	63	61	59	58	57	55	54	,,
Road, 8 ft. ..		686	547	407	277	159	49	− 56	Daily.
One hour more	+	157	137	117	99	81	66	50	,,
One mile less ..	+	57	56	55	52	50	48	46	,,

TABLE XI.—*Continued.*

MULE CARTS (Single File).

Full Stages.

Marching 10 miles. Marching 8 hours.

	F =1	F =·9	F =·8	F =·7	F =·6	F =·5	F =·4	
Road, 16 ft. ..	1647	1317	1000	687	395	117	− 130	Daily.
One hour more	+ 402	333	290	245	202	160	120	,,
One mile less ..	+ 137	135	132	127	123	117	110	,,
Road, 12 ft. ..	1402	1102	830	557	312	90	− 98	Every second day.
One hour more	+ 320	275	240	200	162	125	90	,, ,, ,,
One mile less ..	+ 117	112	107	102	98	90	80	,, ,, ,,
Road, 8 ft. ..	1217	947	700	467	258	73	− 77	Every second day.
One hour more	+ 280	240	202	167	133	100	70	,, ,, ,,
One mile less ..	+ 102	98	92	88	80	73	65	,, ,, ,,

Meeting.

Marching 10 miles (meeting at 5 miles). Marching 7 hours.

Road, 16 ft. ..	1300	1012	730	417	198	− 58	− 250	Daily.
One hour more	+ 385	340	298	252	210	167	125	,,
One mile less ..	+ 140	137	135	133	127	123	112	,,
Road, 12 ft. ..	755	590	422	265	115	− 28	− 162	Daily.
One hour more	+ 225	200	170	148	123	100	77	,,
One mile less ..	+ 82	80	78	76	74	72	70	,,
Road, 8 ft. ..	695	535	380	237	102	− 25	− 142	Daily.
One hour more	+ 207	180	155	130	110	87	67	,,
One mile less ..	+ 75	73	70	67	65	62	60	,,

Short Stages.

Marching 10 miles (5 going and 5 returning). Marching 8 hours.

Road, 16 ft. ..	1812	1450	1115	785	475	180	− 83	Daily.
One hour more	+ 422	350	305	257	213	167	125	,,
One mile less ..	+ 145	142	140	135	127	122	115	,,
Road, 12 ft. ..	1025	842	632	437	252	77	− 90	Daily.
One hour more	+ 240	212	182	155	130	105	82	,,
One mile less ..	+ 87	85	82	80	78	76	75	,,
Road, 8 ft. ..	952	760	565	385	220	67	− 77	Daily.
One hour more	+ 217	190	162	137	112	90	70	,,
One mile less ..	+ 79	77	74	72	69	67	64	,,

TABLE XI.—*Continued.*

PONY CARTS (EKKAS) (Single File). With 400 lbs. loads.

Full Stages.

Marching 10 miles. Marching 8 hours.

	F=1	F=·9	F=·8	F=·7	F=·6	F=.5	F=·4	
Road, 14 ft. ..	1977	1581	1200	825	474	141	−156	Daily.
One hour more	+ 483	400	348	294	243	192	144	,,
One mile less ..	+ 105	162	159	153	147	141	132	,,
Road, 10½ ft. ..	1683	1323	996	669	375	108	−117	Every second day.
One hour more	+ 384	333	288	240	195	150	108	,, ,, ,,
One mile less ..	+ 141	135	129	123	117	108	96	,, ,, ,,
Road, 7 ft. ..	1461	1137	843	561	309	87	−93	Every second day.
One hour more	+ 336	288	243	201	159	120	84	,, ,, ,,
One mile less ..	+ 123	117	111	105	96	87	78	,, ,, ,,

Meeting.

Marching 10 miles (meeting at 5 miles). Marching 7 hours.

Road, 14 ft. ..	1560	1215	876	549	237	−69	−300	Daily.
One hour more	+ 402	408	367	303	252	201	150	,,
One mile less ..	+ 168	165	162	159	153	147	135	,,
Road, 10½ ft. ..	906	708	507	318	138	−33	−195	Daily.
One hour more	+ 270	240	204	177	147	120	93	,,
One mile less ..	+ 99	96	93	91	90	87	84	,,
Road, 7 ft. ..	834	642	456	285	123	−30	−171	Daily.
One hour more	+ 249	216	186	156	132	105	81	,,
One mile less ..	+ 90	87	84	81	78	75	72	,,

Short Stages.

Marching 10 miles (5 going and 5 returning). Marching 8 hours.

Road, 14 ft. ..	2175	1740	1338	942	570	216	−99	Daily.
One hour more	+ 507	420	366	309	255	201	150	,,
One mile less ..	+ 174	171	168	162	153	147	138	,,
Road, 10½ ft. ..	1230	1011	759	525	303	93	−108	Daily.
One hour more	+ 288	255	219	186	156	126	99	,,
One mile less ..	+ 105	102	99	96	94	92	90	,,
Road, 7 ft. ..	1143	912	678	462	264	81	−93	Daily.
One hour more	+ 261	228	195	165	135	108	84	,,
One mile less ..	+ 95	93	90	86	83	80	77	,,

TABLE XI.—*Continued.*

EKKAS (320 lbs. loads) (Single File).

Full Stages.

Marching 10 miles. Marching 8 hours.

	F=1	F=·9	F=·8	F=·7	F=·6	F=·5	F=·4	
Road, 14 ft. ..	3120	2630	2150	1670	1220	800	360	Daily.
One hour more +	540	496	420	360	306	250	198	,,
One mile less .. +	140	138	136	134	132	130	128	,,
Road, 10½ ft. ..	2636	2160	1740	1340	972	616	281	Every second day.
One hour more +	450	392	341	290	238	195	152	,, ,, ,,
One mile less .. +	118	115	112	109	106	103	100	,, ,, ,,
Road, 7 ft. ..	2200	1820	1460	1116	810	513	230	Every second day.
One hour more +	380	335	287	238	198	162	127	,, ,, ,,
One mile less .. +	98	95	92	89	86	83	80	,, ,, ,,

Meeting.

Marching 10 miles (meeting at 5 miles). Marching 7 hours.

Road, 14 ft. ..	2580	2154	1730	1310	914	550	162	Daily.
One hour more +	540	476	420	360	306	250	198	,,
One mile less .. +	140	138	136	134	132	130	128	,,
Road, 10½ ft. ..	1490	1240	1000	750	530	308	95	Daily.
One hour more +	310	276	238	206	173	141	111	,,
One mile less .. +	82	80	79	77	76	74	73	,,
Road, 7 ft. ..	1340	1100	875	657	458	265	80	Daily.
One hour more +	279	243	211	180	150	122	95	,,
One mile less .. +	74	72	70	68	66	64	62	,,

Short Stages.

Marching 10 miles (going and returning). Marching 8 hours.

Road, 14 ft. ..	3440	2820	2400	1890	1400	950	420	Daily.
One hour more +	590	523	462	396	336	275	217	,,
One mile less .. +	144	142	141	140	139	138	137	,,
Road, 10½ ft. ..	1980	1670	1370	1180	800	533	272	Daily.
One hour more +	340	303	261	226	190	155	122	,,
One mile less .. +	85	83	82	80	79	77	76	,,
Road, 7 ft. ..	1780	1480	1210	945	700	460	223	Daily.
One hour more +	301	267	232	198	165	134	104	,,
One mile less .. +	76	74	73	71	70	68	67	,,

TABLE XI.—*Continued.*

COUNTRY BULLOCK-CARTS (Single File).

Full Stages.

Marching 10 miles. Marching 8 hours.

		F=1	F=·9	F=·8	F=·7	F=·6	F=·5	F=·4	
Road 16 ft. ..		812	590	372	155	−40	−250	−450	Daily.
One hour more	+	251	230	202	175	147	120	95	,,
One mile less ..	+	135	133	132	130	129	127	126	,,
Road, 12 ft. ..		700	500	310	130	−42	−202	−355	Every second day.
One hour more	+	220	195	170	145	120	92	75	,, ,, ,,
One mile less ..	+	116	113	110	107	103	100	97	,, ,, ,,
Road, 8 ft. ..		610	430	265	110	−35	−170	−279	Every second day.
One hour more	+	192	167	142	117	100	82	62	,, ,, ,,
One mile less ..	+	100	97	94	91	88	85	82	,, ,, ,,

Meeting.

Marching 10 miles (meeting at 5 miles). Marching 7 hours.

Road, 16 ft. ..		561	360	170	−20	−187	−370	−545	Daily.
One hour more	+	251	230	202	175	147	120	95	,,
One mile less ..	+	135	133	132	130	129	127	126	,,
Road, 12 ft. ..		325	207	98	−10	−115	−212	−307	Daily.
One hour more	+	152	135	117	100	85	67	52	,,
One mile less ..	+	80	78	77	75	74	72	71	,,
Road, 8 ft. ..		295	188	87	−7	−100	−185	−270	Daily.
One hour more	+	137	122	105	87	75	60	47	,,
One mile less ..	+	70	68	67	65	64	62	61	,,

Short Stages.

Marching 10 miles (going and returning). Marching 8 hours.

Road, 16 ft. ..		912	680	450	225	18	−202	−412	Daily.
One hour more	+	263	241	212	183	154	126	100	,,
One mile less ..	+	138	137	136	135	134	133	132	,,
Road, 12 ft. ..		537	394	260	130	4	−120	−235	Daily.
One hour more	+	160	141	122	105	89	70	54	,,
One mile less ..	+	82	80	79	77	76	74	73	,,
Road, 8 ft. ..		486	358	234	114	5	−101	−204	Daily.
One hour more	+	143	128	110	91	78	63	49	,,
One mile less ..	+	72	70	69	67	66	64	63	,,

TABLE XI.—*Continued.*

CAMELS (Single File).

Full Stages.

Marching 10 miles. Marching 6 hours.

		F=1	F=·9	F=·8	F=·7	F=·6	F=·5	F=·4	
Road, 18 ft. ..		665	402	150	−108	−350	−580	−830	Daily.
One hour more	+	430	385	336	297	242	203	158	,,
One mile less ..	+	192	189	187	184	182	179	177	,,
Road, 13½ ft. ..		580	343	126	−94	−290	−476	−675	Every second day.
One hour more	+	357	315	273	235	200	161	112	,, ,, ,,
One mile less ..	+	164	161	158	155	152	149	146	,, ,, ,,
Road, 9 ft. ..		511	297	108	−80	−245	−406	−570	Every second day.
One hour more	+	312	273	235	200	168	137	105	,, ,, ,,
One mile less ..	+	147	143	139	135	131	127	123	,, ,, ,,

Meeting.

Marching 10 miles (meeting at 5 miles). Marching 3 hours.

Road, 18 ft. ..		−625	−753	−858	−1000	−1076	−1190	−1300	Daily.
One hour more	+	430	385	336	297	242	203	158	,,
One mile less ..	+	192	189	187	184	182	179	177	,,
Road, 13½ ft. ..		−340	−408	−468	−546	−616	−657	−737	Daily.
One hour more	+	245	213	185	161	136	108	87	,,
One mile less ..	+	112	111	110	109	108	107	106	,,
Road, 9 ft. ..		−300	−387	−436	−497	−544	−591	−650	Daily.
One hour more	+	220	200	171	147	122	98	77	,,
One mile less ..	+	100	98	97	95	94	92	91	,,

Short Stages.

Road, 18 ft. ..		768	495	232	−34	−290	−529	−791	Daily.
One hour more	+	446	400	349	308	251	211	164	,,
One mile less ..	+	194	192	191	189	188	186	185	,,
Road, 13½ ft. ..		456	284	133	−23	−174	−306	−454	Daily.
One hour more	+	255	221	191	167	141	112	90	,,
One mile less ..	+	113	112	111	110	109	108	107	,,
Road, 9 ft. ..		415	263	120	−20	−148	−273	−400	Daily.
One hour more	+	228	208	177	152	126	102	80	,,
One mile less ..	+	101	100	99	98	97	96	95	,,

TABLE XI.—*Continued.*

PACK MULES (Single File).

Full Stages.

Marching 10 miles. Marching 8 hours.

	F=1	F=·9	F=·8	F=·7	F=·6	F=·5	F=·4	
Road, 12 ft. ..	3200	2680	2090	1520	960	435	− 90	Daily.
One hour more	+ 670	600	522	450	387	305	244	,,
One mile less ..	+ 223	221	219	218	217	216	215	,,
Road, 9 ft. ..	2940	2370	1830	1320	830	364	− 67	Every second day.
One hour more	+ 598	526	454	382	320	260	202	,, ,, ,,
One mile less ..	+ 207	175	170	165	160	155	150	,, ,, ,,
Road, 6 ft. ..	2560	2050	1560	1125	700	306	− 50	Every second day.
One hour more	+ 522	450	387	328	270	220	170	,, ,, ,,
One mile less ..	+ 180	175	170	165	160	155	150	,, ,, ,,

Meeting.

Marching 10 miles (meeting at 5 miles). Marching 6 hours.

Road, 12 ft. ..	1050	1480	1040	620	186	− 175	− 578	Daily.
One hour more	− 670	600	522	450	387	305	244	,,
One mile less ..	+ 223	221	219	218	217	216	215	,,
Road, 9 ft. ..	1200	910	640	380	120	− 122	− 350	Daily.
One hour more	+ 400	360	315	270	230	189	150	,,
One mile less	+ 144	141	138	135	132	129	126	,,
Road, 6 ft. ..	1180	812	667	333	117	− 99	− 297	Daily.
One hour more	− 369	328	283	243	198	162	126	,,
One mile less ..	+ 125	123	121	119	117	115	113	,,

Short Stages.

Marching 10 miles (going and returning). Marching 8 hours.

Road, 12 ft. ..	3560	2920	2300	1700	1110	555	6	Daily.
One hour more	+ 700	630	548	475	406	320	256	,,
One mile less ..	+ 227	225	224	222	221	219	218	,,
Road, 9 ft. ..	2160	1770	1390	1030	670	346	10	Daily.
One hour more	+ 425	377	330	283	240	198	157	,,
One mile less ..	− 151	148	145	142	139	136	133	,,
Road, 6 ft. ..	2060	1595	1246	915	593	290	5	Daily.
One hour more	+ 384	340	297	255	207	170	132	,,
One mile less ..	+ 127	125	123	121	119	117	115	,,

TABLE XI.—*Continued.*

PACK BULLOCKS (Single File).

Full Stages.

		Marching 10 miles. Marching 8 hours.							
		F=1	F=·9	F=·8	F=·7	F=·6	F=·5	F=·4	
Road, 14 ft. ..		1578	1242	918	600	294	0	−285	Daily.
One hour more	+	375	330	291	249	210	171	138	,,
One mile less ..	+	158	154	152	150	148	146	144	,,
Road, 10½ ft. ..		1305	1017	744	480	234	0	−222	Every second day.
One hour more	+	309	270	234	201	168	135	105	,, ,, ,,
One mile less ..	+	134	130	126	122	118	114	110	,, ,, ,,
Road, 7 ft. ..		1110	858	624	400	192	0	−183	Every second day.
One hour more	+	261	231	195	165	138	111	87	,, ,, ,,
One mile less ..	+	112	100	98	96	94	92	90	,, ,, ,,

Meeting.

		Marching 10 miles (meeting at 5 miles). Marching 6 hours.							
Road, 14 ft. ..		826	582	336	102	−126	−342	−561	Daily.
One hour more	+	375	330	291	249	210	171	138	,,
One mile less ..	+	156	154	152	150	148	146	144	,,
Road, 10½ ft. ..		462	320	290	54	−75	−183	−318	Daily.
One hour more	+	219	192	168	144	120	96	78	,,
One mile less ..	+	90	88	87	85	84	82	81	,,
Road, 7 ft. ..		426	291	168	48	−60	−168	−273	Daily.
One hour more	+	192	171	147	126	102	84	66	,,
One mile less ..	+	81	79	77	75	73	71	69	,,

Short Stages.

		Marching 10 miles (going and returning). Marching 8 hours.							
Road, 14 ft. ..		1728	1474	1032	696	378	68	−231	Daily.
One hour more	+	382	348	305	261	220	178	144	,,
One mile less ..	+	158	157	156	155	154	153	152	,,
Road, 10½ ft. ..		980	780	589	398	203	38	−131	Daily.
One hour more	+	229	201	176	151	126	100	82	,,
One mile less ..	+	92	91	90	89	88	87	86	,,
Road, 7 ft. ..		886	701	518	348	184	32	−117	Daily.
One hour more	+	201	179	154	132	107	88	69	,,
One mile less ..	+	83	81	79	77	75	73	71	,,

TABLE XI.—*Continued.*

DONKEYS (Single File).

Full Stages.

Marching 10 miles. Marching 8 hours.

	F = 1	F = ·9	F = ·8	F = ·7	F = ·6	F = ·5	F = ·4	
Road, 10 ft. ..	1575	1140	715	300	− 100	− 485	− 860	Daily.
One hour more +	500	440	385	335	285	235	190	,,
One mile less .. +	262	258	254	250	246	243	240	,,
Road, 7½ ft. ..	1305	930	575	240	− 70	− 380	− 670	Every second day.
One hour more +	415	365	315	270	225	180	145	,, ,, ,,
One mile less .. +	220	214	208	202	196	190	184	,, ,, ,,
Road, 5 ft. ..	1110	785	485	200	− 60	− 315	− 550	Every second day.
One hour more +	355	305	260	220	185	150	115	,, ,, ,,
One mile less .. +	186	180	174	168	162	156	150	,, ,, ,,

Meeting.

Marching 10 miles (meeting at 5 miles). Marching 6 hours.

Road, 10 ft. ..	575	260	− 55	− 370	− 670	− 955	− 1240	Daily.
One hour more +	500	440	385	335	285	235	190	,,
One mile less .. +	262	258	254	250	246	243	240	,,
Road, 7½ ft. ..	340	145	− 40	− 210	− 375	− 550	− 705	Daily.
One hour more +	285	255	225	190	160	133	105	,,
One mile less .. +	152	149	146	143	140	137	134	,,
Road, 5 ft. ..	290	120	− 20	− 170	− 310	− 455	− 600	Daily.
One hour more +	260	230	195	160	130	110	90	,,
One mile less .. +	134	131	128	125	122	119	116	,,

Short Stages.

Marching 10 miles (going and returning). Marching 8 hours.

Road, 10 ft. ..	1775	1316	870	434	14	− 390	− 784	Daily.
One hour more +	525	462	404	352	300	252	204	,,
One mile less .. +	267	265	263	261	259	257	255	,,
Road, 7½ ft. ..	1026	755	500	246	9	− 226	− 458	Daily.
One hour more +	300	267	236	195	168	141	110	,,
One mile less .. +	155	152	150	147	145	142	140	,,
Road, 5 ft. ..	914	672	438	214	2	− 191	− 384	Daily.
One hour more +	273	241	204	168	136	115	95	,,
One mile less .. +	137	134	132	129	127	124	122	,,

TABLE XI. *Continued.*

COOLIES (Single File).

Full Stages.

Marching 10 miles. Marching 9 hours.

	F=·9	F=·8	F=·7	F=·6	F=·5	F=·4	F=·3	
Road, 8 ft. ..	1878	1302	756	228	−282	−780	−1250	Daily.
One hour more	+ 516	444	390	324	270	210	156	,,
One mile less ..	+ 298	290	282	274	266	258	250	,,
Road, 6 ft. ..	1360	937	560	262	−237	−660	−1040	Daily.
One hour more	+ 373	324	281	233	184	146	98	,,
One mile less ..	+ 221	215	209	203	197	191	185	,,
Road, 4 ft. ..	1266	858	492	144	−174	−480	−762	Every second day.
One hour more	+ 348	300	252	204	168	132	96	,, ,, ,,
One mile less ..	+ 204	198	192	186	180	174	168	,, ,, ,,

Meeting.

Marching 10 miles (meeting at 5 miles). Marching 8 hours.

Road, 8 ft. ..	1362	858	366	−96	−552	−990	−1410	Daily.
One hour more	+ 516	444	390	324	270	210	156	,,
One mile less ..	+ 298	290	282	274	266	258	250	,,
Road, 6 ft. ..	774	486	216	−48	−306	−557	−798	Daily.
One hour more	+ 300	258	216	180	150	120	90	,,
One mile less ..	+ 177	174	171	168	165	162	159	,,
Road, 4 ft. ..	684	426	180	−38	−258	−474	−680	Daily.
One hour more	+ 258	222	192	162	126	102	78	,,
One mile less ..	+ 144	142	140	138	136	134	132	,,

Short Stages.

Marching 10 miles (going and returning). Marching 9 hours.

Road, 8 ft. ..	2190	1570	990	422	−120	−654	−1160	Daily.
One hour more	+ 567	488	430	356	297	231	170	,,
One mile less ..	+ 314	310	306	302	298	294	290	,,
Road, 6 ft. ..	1380	1000	648	312	−6	−312	−618	Daily.
One hour more	+ 350	301	252	210	175	140	105	,,
One mile less ..	+ 194	193	192	191	190	189	188	,,
Road, 4 ft. ..	1200	870	564	270	−6	−270	−522	Daily.
One hour more	+ 300	259	224	170	147	120	91	,,
One mile less ..	+ 168	166	164	162	160	158	156	,,

NOTE ON TABLES FOR CAPACITY OF STAGES.

The capacity of a stage, that is the number of vehicles or pack animals that can be economically employed under the given conditions, must not be confused with the strength of a transport unit which is placed under the command of one man, for purposes of discipline and interior economy. Thus after the Tirah Expedition in India a Mule Corps was fixed at approximately 800 mules, in much the same way as universal experience had fixed the strength of a battalion of infantry at 1,000 men. But, as several battalions can be formed into one column, so several mule corps can be associated in one convoy, provided the road and other conditions admit. Indeed in the Thibet Expedition of 1903–04 two, three, or even more mule corps were successfully employed in a single convoy.

In calculating the tables an additional allowance has been included for the practical difficulty experienced in moving off long convoys exactly to time, a difficulty which varies as the length of convoy.

As a large amount of data was available for animal transport, the tables for the various classes have been constructed with considerable confidence. The table for Motor Transport, being based on scantier data, must be considered more in the nature of an approximate estimate.

78. MAXIMUM OF STORES IN MINIMUM OF TIME.

This condition is fulfilled when the product of the capacity multiplied by the length of stage is a maximum.

If A = tabular capacity for the number of marching hours permissible.

m = the correction for 1 mile.

x = length of march.

The maximum of stores will be forwarded in the minimum of time, when $x = \frac{A + 10m}{2m}$.*

The practical value of this adjustment of the length of stage is not as great as would appear. The stages are largely determined by other considerations, and the commander of a force may attach more importance to securing the maximum supply daily, irrespective of the time the stores are *en route*.

79. USE OF TABLE FOR THROUGH CONVOYS.

Having determined the time available for marching, use the table for full stages.

For well-organized convoys, 10 per cent. may be added to the capacity so obtained.

* By the Differential Calculus the expression $[A + m(10 - x)]\,x$ is the maximum when its differential is nought, *i.e.* when $A + 10m - 2mx = 0$.

80. CASUALTIES ON COMMUNICATIONS.

Men and animals on the line of communications have certain advantages over the field force in front, in so far that this work can be made more systematic, their hours of labour and rest being fixed so that a regular routine ensues, while better arrangements can be made for their comfort and well-being at the various posts to which they are allotted. On the other hand they have to work without remission, whatever the weather, as the supply of the army in the field is of paramount importance.

Even with the most careful arrangements and forethought casualties must occur, though under favourable conditions, and with one day's rest in seven, they may not exceed $2\frac{1}{2}$ per cent. per month. Under unfavourable conditions and faulty management the monthly list of casualties may increase tenfold.

We must reckon on about 3 per cent. of minor cases which should return to duty after a few days' rest at the post, and in consequence are not counted as casualties. Should a deficiency in spare prevent the animals being temporarily relieved from work, it is obvious that their chance of recovery is slight, and that, in the majority of instances, they must become casualties.

Similarly, if the transport is deprived of its weekly rest, when the animals obtain a respite from work, and their equipment can be overhauled and minor defects made good, the number of trivial cases of illness or galling will be largely increased, and these cases will rapidly develop into actual casualties.

Thus the question of rest and casualties must, to some extent, be considered together when deciding what amount of spare should be allowed at the various posts.

The following rough empirical rules were deduced from the experiences of the Thibet Expedition of 1903–04:—

If P be the monthly percentage of casualties, W the number of working days for one day's rest.

Then $$P = \frac{24 - \frac{100}{W}}{3}.$$

For each of the undermentioned unfavourable conditions add $\frac{1}{2}P$:—

Trying climatic conditions.
Badly organized communications.
Animals underfed.

When the transport is extemporized with partially trained and poorly disciplined establishments, the percentage of casualties obtained by the above rule may be increased by 50 per cent.

81. REST.

It is generally admitted that an average of one day's rest a week is necessary, if the work is to be sustained without loss of efficiency, and this is as true on the lines of communications as elsewhere.

This weekly day of rest can be given in one of two ways. We may either cease work for a whole day weekly, thus using the line to six-sevenths of its capacity on the average, or we may increase the percentage of spare at each post on the line, so that each animal obtains the same proportion of rest, while the line is worked to its full capacity.

In both cases there is a certain reserve of power available for emergencies, though its application is different.

When the rest is obtained by ceasing work once a week, it is evident that by foregoing this rest the output in any week will be increased by one-sixth, but, as the expedient can only be adapted when the rest day arrives, a sudden demand for a temporary increase of supplies cannot always be dealt with.

When the rest is provided by increasing the percentage of spare animals at each post, such a demand can be immediately met to some extent by working extra hours, but the increased output per day is limited by the number of spare animals available.

But in either case, although it is reassuring to have a reserve of power available for emergencies, this reserve must be very sparingly utilized, like the power of forced marching, or the line of communications, as a whole, will pay dearly, by its greatly swollen casualty list, for the temporary increase of power gained by depriving men and animals of the rest on which so much of their efficiency depends.

In the first method the proportion of spare may be reduced to a minimum, with a consequent reduction in the transport required for the supply of the line itself in distinction to the force in front, but the line is only worked to six-sevenths of its normal capacity.

In the second method the proportion of supplies required for the line is increased, but the full capacity is maintained.

As the capacity of the line, as a whole, depends on that of its limiting stage, it follows that the second method gives superior results, until the additional food required by the increased number of spare men and animals ahead of the limiting stage exceeds one-seventh of the capacity of that stage.

82. PROPORTION OF SPARE.

For work on the line of communication it is necessary to provide at each stage a proportion of spare animals, to take the place of those suffering from slight ailments, but which may confidently be expected to return to duty after a few days' rest at the post, and

also to temporarily take the place of casualties while drafts are being sent from the base, or nearest depôt. For the former purpose it is desirable to allow of 3 per cent., while for the latter an additional 2 per cent. should suffice with good arrangement.

It is generally laid down that the allowance of spare should be 10 per cent., but the regulation in India,* while advocating 10 per cent. on the whole, specifies that only 5 per cent. should be located at each post, and the balance kept massed at the base, from which drafts can be sent up the line to replace casualties as they occur. This practically means that the stages are worked with 5 per cent. spare, which may be considered the minimum, and which cannot be further reduced without loss of efficiency.

By keeping the percentage of spare as low as possible, we decrease the amount of food which the line has to carry for its own use, and theoretically increase the proportion of the available transport which can be devoted to the end of forwarding supplies for the army in front.

But, as the capacity of a line of communication depends on many other factors besides the limitation due to the food it consumes, a reduction of spare at the posts does not necessarily entail an increase of capacity, and may, indeed, in many cases produce the opposite result.

In practice the proportion of spare animals should lie between 5 and 22 per cent., as useful minimum and maximum percentages, though in a few exceptional cases it may have to be still further increased. In this, as in so many questions in war, no hard-and-fast limit can be laid down, and the special circumstances of the case must be taken into consideration, but generally speaking it is undoubtedly sound to keep the proportion of spare at the posts as low as possible compatible with efficiency.

APPORTIONMENT OF TRANSPORT TO STAGES.

83. DATA NECESSARY FOR APPORTIONMENT OF TRANSPORT.

Before proceeding to calculate the proportion of transport required at the various stages, we must assemble certain data as a basis of computation.

1. The percentage of spare, p, to be allowed at each post.

2. The percentage of spare, q, which will actually accompany each convoy.

3. For full stages only, the scale of kits to be carried for the convoy establishment.

* Quartermaster-General's Circular, 1908.

4. The scale of food to be provided daily from the source of supply for men and animals, viz., their daily requirements, less what can be obtained locally.*

5. The source of supply, whether from the base, as usual, or from the front which may sometimes be feasible and advantageous.

6. The method of working the stage, *i.e.* whether the transport stationed at a post is to work "forwards," on the stage towards the front, or "backwards," on the stage towards the rear, or base.

7. The system of staging to be employed, viz.:—Full stages, meeting, or short stages.

84. Proportion of Transport at Successive Stages.

It is generally stated that the transport on each stage towards the base must be increased in geometrical progression, but it is more accurate to say that this progression is towards the source of supply, as the latter is not necessarily the base, though generally so.

Similarly we are told to work from the front towards the rear when estimating the strength of transport on each successive stage. This again would be more accurately expressed as working from the most distant point fed from any given source of supply towards that source. If certain posts are supplied from fertile districts in front, the progression may run from front to rear, or may even cease altogether on certain stages.

In all cases where there is an increase, such increase is in the nature of a geometrical progression depending on a "First Term" and a "Ratio of Increase," the latter being the percentage of increase plus unity.

To determine the amount of transport required at each stage, we require a "First Term for Totals," which represents the total amount necessary to carry one through unit on the most distant stage.

To gauge the net capacity of a stage, we need a "First Term for Convoy," which represents the convoy required to carry the above through unit.

Although various first terms may thus be employed to facilitate calculation, the same ratio of increase is used with all.

It must be remembered that the whole of the transport for a stage is considered to be located at one post for full stages, or short stages, while for the meeting system half is located at each post at either end of the stage. This affects the ultimate distribution of the transport, but does not affect the method of calculation.

* If grazing be taken into account, it should not be considered equivalent to more than half a ration.

The progression for a system of n stages may be shown as follows, when B is the first term, and C the ratio of increase :—

	Supply from Rear.			Supply from Front.*		
Post.	Stages in Order of Calculation.	Working. Forwards.	Working. Backwards.	Stages in Order of Calculation.	Working. Forwards.	Working. Backwards.
Front		O	B		O	BC^{n-1}
	One			n		
No. 1.		B	BC		BC^{n-1}	BC^{n-2}
	Two			$n-1$		
No. 2.		BC	BC^2		BC^{n-2}	BC^{n-3}
	Three			$n-2$		
No. 3.		BC^2	BC^3		BC^{n-3}	BC^{n-4}
—	—	—	—	—	—	—
	$n-2$			Three		
No. $(n-2)$		BC^{n-3}	BC^{n-2}		BC^2	BC
	$n-1$			Two		
No. $(n-1)$.		BC^{n-2}	BC^{n-1}		BC	B
	n			One		
No. (n).		BC^{n-1}	O		B	O

* It must be noted that when the supply is from the front, there may be no progression, see Section 85.

85. DETERMINATION OF FIRST TERMS AND RATIO OF INCREASE.

A simple line is one on which the whole of the supply (other than what is obtained at the posts themselves) is wholly from the rear, or wholly from the front.

A compound line draws its supply partly from the front and partly from the rear.

There are some 18 variations on a simple line, depending on the source of supply, the way in which the stages are worked, and the system adopted.

On a compound line there are also many variations, but the method of obtaining the first terms and ratio of increase are similar.

To facilitate calculation, a table is subjoined, which shows how the problem should be approached in each of the 18 cases. The calculation is based on 100 loaded units, carts, camels, or whatever the transport may be, and any deductions for kits, food, etc., must be expressed in similar units. The number of through units for the force, S, is obtained by deducting the sum of columns 6 and 7 from 100.

The first term for totals is $\frac{\text{column } 5 \times (100+p)}{S}$.

The percentage of increase, where such exists, is the food required for one day, on the specified scale by the first term of totals, expressed as a decimal of the same unit of transport.

The ratio of increase is this percentage of increase plus unity.

The first term for convoy is $\frac{100+q}{S}$, except on narrow roads with the full stage system when it is $\frac{2 \times (100+q)}{S}$.

The first term for loads is unity.

TABLE.

To Facilitate Calculation of First Terms and Ratio of Increase.

p = total percentage of spare at post.
q = percentage of spare with actual convoy.
S = through supply for the force is 100 less, the sum of the deduction in columns 6 and 7:

1 Case.	2 Supply from	3 Working.	4 System.	5 Multiplier.	6 Deductions for Kits for	7 Deductions for One Day's Food for	8 Percentage of Increase.
1	Rear.	Forwards.	Full Stages.	2	$100 \div q$	$100 \div q$	Required.
2			Meeting.	2	—	$100 \div p$	,,
3			Short Stages.	1	—	—	,,
4		Backwards.	Full Stages.	2	$100 \div q$	$100 \div 2p - q$	,,
5			Meeting.	2	—	$100 \div p$	,,
6			Short Stages.	1	—	$100 \div p$	,,
7	Front* (Under limit).	Forwards.	Full Stages.	2	$100 \div q$	$100 \div 2p - q$	Nil.
8			Meeting.	2	—	$100 \div p$	,,
9			Short Stages.	1	—	$100 \div p$	,,
10		Backwards.	Full Stages.	2	$100 \div q$	$100 \div q$	,,
11			Meeting.	2	—	$100 \div p$	,,
12			Short Stages	1	—	—	,,
13	Front* (Over limit).	Forwards.	Full Stages.	2	$100 \div q$	$100 \div 2p - q$	Required.
14			Meeting.	2	—	$100 \div p$	,,
15			Short Stages.	1	—	$100 \div p$	,,
16		Backwards.	Full Stages.	2	$100 \div q$	$100 \div q$	,,
17			Meeting.	2	—	$100 \div p$	,,
18			Short Stages.	1	—	—	,,

* In the case of supply from the front, the case is "under the limit," when the total supplies for the transport at all the posts (less that nearest the source of supply) does not exceed the through supply for the front, in which case no additional transport is required. If it does exceed the through supply for the front, it is "over the limit" and additional transport is required.

EXAMPLE.—*Full Stage.*—The stage is worked forwards with a supply from the rear on the full stage system with camels. The percentage of spare is 5 per cent., of which 3 per cent. accompany the convoy. The kits and food, averaged per camel, come to 10 lbs. and $14\frac{1}{4}$ lbs. respectively. The road is broad. To find the first terms for totals and capacity and the ratio of increase.

Here $p=5$, and $q=3$.

The deductions are 103×10 for kits or 1,030 lbs.

$103 \times 14\frac{1}{4}$ for food or 1,468 lbs.

The total 2,498 lbs. requires $\frac{2498}{400}$, or 6·25 camels.

So $S = 100 - 6{\cdot}25 = 93{\cdot}75$.

First term for totals $= \frac{2 \times 105}{93{\cdot}75} = 2{\cdot}24$.

Percentage of increase $= \frac{2{\cdot}24 \times 14\frac{1}{4}}{400} = {\cdot}08$.

Ratio of increase = 1·08.

First term for convoy $= \frac{103}{93{\cdot}75} = 1{\cdot}10$ say.

EXAMPLE.—*Meeting.*—The stage is worked forwards with supply from the rear on the meeting system with camels. The percentage of spare is 5 per cent., of which 2 per cent. accompany the convoy. The food, averaged per camel, comes to $14\frac{1}{4}$ lbs. To find the first terms for totals and capacity, and the ratio of increase.

Here $p=5$, and $q=2$.

The deduction is $105\times14\frac{1}{4}=1{,}496$ lbs.

Which is $\frac{1496}{400}$, or 3·74 camel loads.

So $S=100-3\cdot74=96\cdot26$.

First term for totals $=\frac{2\times105}{96\cdot26}=$ say 2·18.

Percentage of increase $=\frac{2\cdot18\times14\frac{1}{4}}{400}=\cdot078$.

Ratio of increase $=1\cdot078$.

First term for convoy $=\frac{102}{96\cdot26}=1\cdot06$.

EXAMPLE.—*Short Stages.*—The stage is worked forward with supply from the rear on the short stage system, with camels.

The percentage of spare is 5 per cent., of which 2 per cent. accompany the convoy. The food arranged per camel comes to $14\frac{1}{4}$ lbs.

To find the first terms for totals and capacity, and the ratio of increase.

Here $p=5$, and $q=2$.

There are no deductions.

So $S=100$.

First term for totals $=\frac{105}{100}=1\cdot05$.

Percentage of increase $=\frac{105\times14\frac{1}{4}}{400}=\cdot0374$.

Ratio of increase $=1\cdot0374$.

First term for convoy $=\frac{102}{100}=1\cdot02$.

86. TABLE OF RATIOS.

Having found the ratio as in the last section, those for successive stages may be taken from any of the published tables, such as the amount of one pound sterling at various rates of interest, or they may be calculated by multiplying unity by the ratio, the product of the ratio again, and so on.

Having found the ratio for each stage, it is well to fill up in an adjacent column the sum of these ratios, as the sums are useful for finding the total transport in front of any given stage, and also for

hasty calculations regarding the transport required for the supply of the garrison of posts. A third column giving the sum of these sums is useful for the approximate determination of the total transport required for the supply of the garrisons.

The following table gives the ratios and their sums for a short line of six full stages, the data being as in the first example of Section 85 :—

TABLE FOR RATIO OF 1·08.

Stage.	For Front.		For Posts.	
	Ratio.	Sum.	Ratio.	Sum.
1	1·000	1·000	—	—
2	1·080	2·080	1·000	1·000
3	1·166	3·246	2·080	3·080
4	1·260	4·506	3·246	6·326
5	1·360	5·866	4·506	10·832
6	1·470	7·336	5·866	16·698

The use of the table may be illustrated as follows :—

1. Particulars for fourth stage, when 100 camel loads a day are delivered at the front :—

Transport for stage	$2{\cdot}24\times100\times1{\cdot}26=283$
Convoy for stage	$1{\cdot}10\times100\times1{\cdot}26=139$
Loads forwarded	$1\times100\times1{\cdot}26=126$
Total camels required for first four stages	$2{\cdot}24\times100\times4{\cdot}506=1010$

2. Particulars for fourth stage for supply of posts at an average of three camel loads each :—

Transport for stage	$2{\cdot}24\times3\times3{\cdot}246=22$
Convoy for stage	$1{\cdot}10\times3\times3{\cdot}246=11$
Loads forwarded	$1\times3\times3{\cdot}246=10$
Total camels required for first four stages	$2{\cdot}24\times3\times6{\cdot}326=46$

The totals on any stage are the sum of items 1 and 2 ; thus :—

Total convoy on fourth stage ..	$=139+11=150$
Loads forwarded	$=126+10=136$

87. WORKING SIX DAYS A WEEK.

If the transport is only worked six days a week, the average daily delivery at the front will be only six-sevenths of that forwarded on a single working day. So that, if the average requirements are 100 camel loads a day, the stage must be able to forward 116·7 loads each working day.

The first terms then remain unaltered, but the ratio is altered, as one-sixth additional food for the transport must be carried each working day, to provide for the rest day.

The percentage of increase in Section 86 being ·08, it must accordingly be raised one-sixth, and becomes 1·0933.

TABLE FOR RATIO 1·0933.

Stage.	For Front.		For Posts.	
	Ratio.	Sum.	Ratio.	Sum.
1	1·000	1·000	—	—
2	1·094	2·094	1·000	1·000
3	1·196	3·289	2·094	3·094
4	1·307	4·596	3·289	6·383
5	1·429	6·024	4·596	10·978
6	1·562	7·587	6·024	17·002

To deliver at the front 100 loads a day, we must allow for 116·7 loads each working day.

So for the fourth stage we require 2·24×116·7×1·307, or 342 camels.

It must be noted that the resulting distribution of transport is the same as if we allowed one-sixth additional spare for each stage.

88. TRANSPORT FOR SUPPLY OF POSTS.

This may be calculated by treating each post in succession as if it were the terminus of a line, or can usually be obtained with sufficient accuracy for preliminary investigation by using a table of sums of ratios, and so finding the transport at each post directly.

We will assume camel transport and a line of six stages, as before, worked by full stages forwards, six days a week, the kits of establishments averaging 10 lbs., and the food requirements for the convoy 14¼ lbs. per camel, the supply being from the rear.

The first term for totals is 2·24, for convoy 1·10, for loads 1.

The ratio is 1·0933.

The five posts in order from the front require 3, 2, 5, 2, 3 camel loads daily, or allowing for convoys six days a week, 3·5, 2·4, 5·9, 2·4 and 3·5 loads per working day.

(*a*). DETAILED METHOD.

Ratios Multiplied by Loads.

No. of Post.	I.	II.	III.	IV.	V.	VI.
	—	3·50	3·83	4·18	4·58	5·00
	—	—	2·40	2·63	2·87	3·14
	—	—	—	5·90	6·46	7·05
	—	—	—	—	2·40	2·63
	—	—	—	—	—	3·50
Loads forwarded	—	3·50	6·23	12·71	16·31	21·32
For convoy. Loads×1·10 ..	—	4	7	14	18	24
For transport. Loads×2·24 ..	—	8	14	29	37	48

(*b*). APPROXIMATE METHOD.

Average Load per Post per Working Day is 3·5 Camels.

Sums of Ratios multiplied by Average Load.

No. of Post.	I.	II.	III.	IV.	V.	VI.
Loads forwarded	—	3·50	7·33	11·51	16·09	21·09
For convoy. Loads×1·10 ..	—	4	8	13	18	24
For transport. Loads×2·24 ..	—	8	17	26	37	48

When using the approximate method and the requirements of any post are greatly in excess of the average, leave that post out when calculating the mean, and treat the excess over the mean by the detailed method.

For instance, if Post III. required 12 loads daily (14 per working day) instead of 5 loads, take the average for posts I., II., IV. and V., which comes to 2·5 loads daily or say 3 loads per working day.

Use the approximate method for an average of 3 loads per post including III., and then calculate for the balance of 11 loads required at III.

89. TRANSPORT ON A SIMPLE LINE.

The transport required on each stage is the sum of that required for the supply of the posts plus what is required to supply the force in front.

Assume as in preceding section that we are dealing with camels, and a short simple line of six stages, worked forwards by the full stage system, the supply being from the rear, and that the daily requirements average 14¼ lbs., and the proportion of kits for the men accompanying the convoy 10 lbs. per camel. Further assume that the line is worked six days a week, the seventh day being allowed for rest, and that the front requires 90 loads daily, or 105 loads per working day.

The first terms, calculated, as in Section 85, are :—

For totals 2·24, for convoy 1·10, for loads 1·00.

The ratio of increase, see Section 87, is 1·09333, and the Table of Ratios will be found in the same section. The number of camels required for the posts is given in Section 88.

The distribution will be as follows :—

Post.	For Supply of Posts.	For Supply of Front.	Total.
I.	—	236	236
II.	8	258	266
III.	14	282	296
IV.	29	308	337
V.	37	336	373
VI.	48	368	416
Totals	136	1,788	1,924

The total for the line can be determined very closely by the use of the sums of ratios.

For posts	2·24×3·5×17=134
For front	2·24×105×7·587=1785
Total	1919

90. CHANGE OF SYSTEM, OR SCALE OF FOOD.

If the class of transport remains the same while only the system of working, or scales of food or kits be altered, calculate the new first terms and ratios for the new system or scale. Then proceed in one of the two following methods :—

(*a*). Treat the altered portion as a new line which has to deliver at the last post of the original system or scale, the loads required for the front and for all the transport and posts of the original system.

In this connection it must be noted that the ratio opposite any post in the table represents the loads to be forwarded from that post in order to deliver a unit load at the front, while the ratio of the next post towards the source of supply represents the loads to be received. Thus in Section 87, opposite Post V., we have the ratio for the front 1·429, and for the posts 4·596. These represent loads to be forwarded from Post V. Opposite Post VI. we have 1·562 and 6·024 respectively, which represent the loads to be forwarded from Post VI. and received by Post V.

The total transport at Posts I. to V., inclusive, is, however, found from the sum of the ratios opposite Post V. in the table.

(*b*). Alter the Table of Ratios to suit the new conditions, and use for each system, or scale, the first terms pertaining to it.

For instance, if we assume that the last stage in Section 89 is to be divided into two, and worked on the short stage system forwards, the same scale of food being required from the rear, and that the spare with the convoy is reduced to 2 per cent., we find from Section 85 that the first terms and ratios are as follows :—

First term for totals 1·05, for convoy 1·02, for loads 1·00.

Ratio 1·0436 (working six days a week).

Stage.		For Front. Ratio.	For Front. Sum.	For Posts. Ratio.	For Posts. Sum.	First Terms.
1	..	1·000	1·000	—	—	
2	..	1·094	2·094	1·000	1·000	For totals 2·24. Convoy 1·10. Loads 1·00.
3	..	1·196	3·289	2·094	3·094	
4	..	1·307	4·596	3·289	6·383	
5	..	1·429	6·024	4·596	10·978	
6	..	1·562	14·412	6·024	29·440	Totals 1·05. Convoy 1·02. Loads 1·00.
7	..	1·630	16·042	7·587	37·027	

The ratio "for the front" and "for posts" remains unaltered down to, and including, the sixth stage.

That for the front in the seventh stage is found by multiplying 1·562 by the new ratio, viz. 1·0436; while that for posts is 1·562 added to 6·024.

In sums for the front

$$14{\cdot}412 = 1{\cdot}562 + 6{\cdot}024 \times \frac{2{\cdot}24}{1{\cdot}05},$$

and

16·042 is 14·412+1630.

In sums for the posts

$$29{\cdot}440 = 6{\cdot}024 + 10{\cdot}978 \times \frac{2{\cdot}24}{1{\cdot}05},$$

and

$$37{\cdot}027 = 29{\cdot}440 + 7{\cdot}587.$$

91. CHANGE OF CLASS OF TRANSPORT.

Calculate the first terms and ratio for the new class of transport.

Treat the portion of the line used by the new class of transport as a separate line which has to deliver at the last post of the original portion the loads required at the front, and for all the transport and posts of the original portion.

For instance, assume that the first four stages of the line in Section 89 are worked by camels as before, while on the remaining stages mule carts carrying 800 lbs. each are to be employed.

From the table of ratios for camels, see Section 87, we see that the camel loads to be delivered at Post IV. are 1·429 for each camel load which arrives at the front. But 1·429 camel loads represents the load of $1{\cdot}429 \times \frac{400}{800}$ mule carts. Thus to deliver one camel load at the front we want ·7145 mule-cart loads forwarded to Post IV.

So in constructing a table of ratios of the stages worked by mule carts, the ratio for the first stage, the old fifth stage, is ·7145 instead of unity. That for the second stage is ·7145 multiplied by the ratio for mule carts.

92. SUPPLY FROM THE FRONT ON A SIMPLE LINE.

Suppose the line of six stages worked forwards by camels on the full stage system, and that the allowance for kits and food averages 10 and 17 lbs. respectively. Working six days a week the average food per camel would be say 20 lbs. Assume that 90 camel loads daily have to be forwarded to the force from the rear, and that three loads are required for each post on the average; this means 105 and 3·5 loads respectively per working day.

Find the first terms, see Section 85, Case 7.

They are for totals 2·29 for convoy 1·125.

The ratio will be unity as long as the stages fall below the limit, and 1·1146 beyond this limit.

(*a*). *Below the Limit.*

Each stage will require $1 \times 105 \times 2{\cdot}29$, or 241 camels.

Each post will require $1 \times 3{\cdot}5 \times 2{\cdot}29$, or 8 camels.

The table of ratios will be as follows :—

Stages Reckoned from the Front.	For Front.		For Posts.	
I.	1·000	6·000	5·000	15·000
II.	1·000	5·000	4·000	10·000
III.	1·000	4·000	3·000	6·000
IV.	1·000	3·000	2·000	3·000
V.	1·000	2·000	1·000	1·000
VI.	1·000	1·000	—	—

The total number of camels required will be :—

For front	$6 \times 105 \times 2{\cdot}20$	= 1442
For posts	$15 \times 3\frac{1}{2} \times 2{\cdot}20$	= 121
Total		1563
Required for Stage I.		241
Balance		1322

As there are available the 105 unladen camels, which carried stores to the front, or sufficient to supply $105 \times 400 \div 20$, or 2,100 camels, the line is below the limit.

(*b*). *Above the Limit.*

When the total number of camels, reckoning from the rearmost stage, less those at that stage, come to more than 2,100, each succeeding stage is increased by the ratio 1·1146.

Thus, if the line consisted of ten stages, the total transport required for eight stages would be 2,152, and for nine stages 2,447 camels. Deducting in each case 241, we get balances of 1,911 and 2,206 camels.

The 105 camels which carried stores for the front, and otherwise, return unladen, and can carry food for 2,100 camels, which would suffice for the supply of eight stages.

Thus, for Stages II. to X., reckoned from the front, there would be no ratio of increase, while for Stage I. the ratio would be 1·1146, as two stages are beyond the limit.

The transport for Stage II. would have to be increased to deliver food for 2,206 – 2,100, or 106, camels, *i.e.* by $106 \times \frac{20}{400}$ or 5·3, say 6 camel loads, requiring 14 additional camels.

Stage I. would require extra transport amounting to $14 \times 1{\cdot}1146$ camels

93. A COMPOUND LINE.

This is a case where the supply is partly from the front, and partly from the rear, and is of frequent occurrence when the line of communications passes through isolated fertile districts.

Assume a line of six stages worked by camels on the full stage system. The kits average 10 lbs. per camel. The average food required is 5·14 lbs. from the rear, and 17·13 lbs. from the front per camel per day, or working six days a week, 6 and 20 lbs. respectively per working day. The percentage of spare is five, of which three accompanies the convoy. Each post requires 3·5 loads, and the front 105 loads per working day.

For the supply from the rear, Case 1 of Section 85, the first terms are, for totals 2·19, for convoy 1·075, while the ratio is 1·033.

For the supply from the front, Case 7 of Section 85, the first terms

are, for totals 2·20, for convoy 1·125, while the ratio is 1·1146 (when beyond the limit).

TABLE OF RATIOS, SUPPLY FROM THE REAR.

Stage.	For Front.		For Posts.	
I.	1·000	1·000	—	—
II.	1·033	2·033	1·000	1·000
III.	1·067	3·100	2·033	3·033
IV.	1·103	4·203	3·100	6·133
V.	1·139	5·342	4·203	10·336
VI.	1·177	6·519	5·343	15·679

Total camels for front	.. $6{\cdot}519 \times 105 \times 2{\cdot}19$	= 1500
,, ,, for posts	.. $15{\cdot}679 \times 3\frac{1}{2} \times 2{\cdot}19$	= 121
Total	.. .. ..	1621
Deduct for first stage ..	.. .. ..	230
Balance ..	.. .. ..	1391

Supply from the Front.

(*a*). *Under the Limit.*

There are 105 camels carrying stores for the front, of which $105 \times \frac{1{\cdot}075}{1{\cdot}125}$, or 100, are available for carrying food back towards the rear.

But 100 camel loads would supply $100 \times \frac{400}{20}$, or 2,000 camels, while there are only 1,391 to be provided for.

So the line is under the limit and no modification of the table of ratios is necessary, the camels provided for the supply from the rear sufficing also for the supply from the front.

(*b*). *Over the Limit.*

This case is much more complicated, but as a matter of practice the supply from the front is generally restricted to such stages as can be worked under the limit, the remaining stages, which it must be noted are towards the rear, being more easily, and often more economically, supplied from the rear.

If, however, it is desired to supply all the stages from the front, the procedure is as follows :—

Find for each stage, the totals for supply from the rear, loads from the rear, and power towards the rear, which is obtained by dividing the totals from the rear, by the first term for totals from the front. Find next the food required from the front for the totals at each stage, and note opposite each stage how far this falls short or exceeds the power.

This indicates the limit.

In front of this point there is surplus power for supply from the rear, and deficient power for supply from the front and *vice versâ*.

Find the additional camels required to supply the deficiency of power from the front.

Find the additional camels required rearward of the limiting point to supply the above from the rear.

Again repeat the process, once or more often, until it is found that the successive corrections are less than one camel load.

The totals for each stage are thus established.

The accuracy of the calculation can be checked as follows :—

The camels on Stage I. should suffice for carrying the supply from the front for all the transport and posts in rear of that stage, and similarly those on Stage VI. should suffice for carrying the supply from the rear for the force, the transport and posts in front of that stage.

94. POWER AND EFFICIENCY OF A LINE.

The power of a line of communications may be measured by the number of loads delivered daily at the front for the supply of the force, after deducting everything required for the supply of the line itself, including the garrisons and establishments at posts.

The efficiency may be judged from the number of units of transport required to deliver at the front a power of one unit load daily.

95. THE POWER OF A GIVEN LINE.

This can readily be determined by means of the tables for capacity of stages and a table of ratios.

The method will be illustrated by an example.

We will assume a line of six stages worked forwards by camels, with supply from the rear, six days a week. The kits and food requirements per day come to 10 lbs. and $14\frac{1}{4}$ lbs. per camel, the latter being 16·63 lbs. per working day. Five per cent. spare are allowed, of which three accompany the convoys. Each post requires, on the average, $3\frac{1}{2}$ loads per working day.

The nature and length of each stage is given below, and its capacity is determined by the method given in Section 77.

Stage.	Road Factor.	Mean Width of Road. Feet.	Length of Stage. Miles.	Capacity.
I.	·9	18	$10\frac{1}{4}$	355
II.	·8	$13\frac{1}{2}$	$6\frac{1}{2}$	678*
III.	·8	18	$8\frac{3}{4}$	384
IV.	·9	18	10	402
V.	1·0	18	11	473
VI.	1·0	18	$11\frac{1}{2}$	377

* Every alternate day.

The capacity of any stage, less the camels required for the post, divided by the product of the first term for convoys, multiplied by the corresponding ratio for the supply to the front, gives the power of the line per working day. Six-sevenths of this is the average daily power, if the transport is only worked six days out of seven.

This further procedure is as below :—

Stage.	(a). Total Capacity.	(b). Required by Post.	(c). Capacity for Front.	(d). Ratio.	(e). Power. For Working Day.	(e). Power. Daily Average.
I. ..	355	—	355	1·000	322	276
II. ..	339*	4	335	1·094	278	239
III. ..	384	7	377	1·196	286	245
IV. ..	402	14	388	1·307	270	231
V. ..	473	18	455	1·429	289	247
VI. ..	377	24	351	1·562	204	174
How arrived at.	Already found.	Section 88 (Convoy).	$a-b$	Section 87.	$\frac{c}{d \times 1{\cdot}10}$	$\frac{6}{7}e$

* 678 every second day, equivalent to 339 daily.
The first term for convoy is 1·10.

It is obvious that the sixth stage is the worst, and limits the daily power to 174 camel loads delivered at the front.

The transport for the various stages can be now calculated to deliver 174 loads a day at the front on the average, or 204 loads every working day.

Camels for supply for front ..	$=7{\cdot}59\times204\times2{\cdot}24=$	3468
Camels for supply of posts ..	$=17\times3{\cdot}5\times2{\cdot}24=$	134
Total		3602

The number of camels to deliver 1 load at the front is

$\frac{3602}{174}$, or 20·7.

It will be obvious that by this method the power of the line as limited by any stage can be separately determined by the capacity tables and table of ratios, without having to calculate for the line in detail.

96. LINE FOR A GIVEN POWER.

Given the average daily power required, increase this proportionately to get the power required per working day, and multiply by the first term for convoys. This gives the total capacity required for the first stage.

Then knowing the road factor and mean width of road, calculate the length of stage as in Section 77.

For the second stage multiply the capacity of the first stage by the ratio of increase, and add the convoy required to supply the first post. The sum gives the capacity required for the stage.

For the third, and succeeding stages the procedure is similar, in each case the corresponding ratio being used.

If, as is likely in practice, it is impossible or inconvenient to locate any post so as to secure the proper length of stage, the stage must be shortened with a consequent loss of efficiency, or the decreased capacity of the stage, if lengthened, must be made good by adopting one of the expedients hereafter discussed.

97. FLUCTUATIONS IN POWER.

It is found in practice that the number of loads transmitted varies from day to day, according to the weather, and other conditions. Hence, to provide sufficient transport to deal with the maximum capacity on a fine day, will result in a considerable portion of it remaining idle in bad weather. This may be justifiable in exceptional circumstances, as, for instance, when the line is liable to interruption, and it is necessary to get through a certain amount of stores before this contingency occurs. But, on the other hand, to attempt to provide for very unfavourable circumstances, is to unduly limit the power of the line.

If the limiting stage, the worst as regards the power of the line, is designed for the capacity obtainable in twelve working hours under favourable circumstances, sufficient provision will exist for ordinary fluctuations. The working hours can be increased up to a maximum of fourteen, but under very unfavourable conditions the extra time for marching would not exceed one hour, but even with this the average power of the line should be maintained.

In Section 95 we saw that the capacity of the sixth stage was 377 camels, representing a power of 174 camel loads at the front. Under unfavourable circumstances the capacity for 12 working hours would fall to 118 camels and the power to 46 loads. But $\frac{3}{4}$ hour extra would bring the capacity, hence the power, to their previous figures. Under very unfavourable conditions, the capacity with 1 hour's extra work, would be 181, equivalent to a power of 90 loads. With $1\frac{1}{2}$ hours' work the full power would be obtained, and this should be possible, provided the very unfavourable conditions were not of too frequent occurrence.

If the season was such that fine days were the exception, this fact should be taken into consideration in determining the road factor.

It must also be remembered that, especially with wheeled transport, much, and continuous, traffic causes a deterioration of the road surface, and by lowering the road factor also decreases the capacity of stages and hence the power of the line.

98. TRANSPORT EXPEDIENTS FOR INCREASING THE POWER.

Under these are included various expedients other than engineering expedients. Many of these can be applied to any stage or to the line as a whole, but for the sake of clearness each will, for the most part, be considered with reference to the limiting, or sixth, stage in the line given in Section 95. Some of the expedients, however, are only suited for special cases, and do not admit of general application.

99. ALTERING THE LENGTH OF STAGE.

If the line has been designed with reasonable care, it is unlikely that any great alteration can be made in the sites of posts, but it frequently happens that minor changes are possible, while still adhering to the actual locality originally decided on.

By a small alteration in the position of Post V. in Section 95, or in that of the transport storeyard attached to it, we could make the fifth and sixth stages each $11\frac{1}{4}$ miles long, instead of 11 and $11\frac{1}{2}$ respectively.

The alteration would increase the capacity of the sixth stage from 377 camels to 425 camels, and consequently the average and daily power of the line to 200 loads a day.

This would represent an increase of about 15 per cent.

100. CHANGING THE CLASS OF TRANSPORT.

Assuming that it is practicable to use bullock carts on the sixth stage substitute these for camels.

The capacity of the stage for bullock carts is 609, which would be equivalent to $609 \times \frac{960}{400}$, or 1,461 camels in gross carrying power.

The effect would be that the limiting stage would no longer be the sixth, but the fourth, which gives an average daily power of 231 camel loads.

The power of the line would thus be increased 32 per cent.

As a matter of fact a convoy of 205 carts would suffice to provide a daily average of 231 camel loads at the front.

101. ADDING FAST MOVING TRANSPORT.

This expedient can only be adopted if the stage is being worked by slow-moving transport.

On the sixth stage of the line given in Section 95, a convoy of 377 camels gives an average power of 174 camel loads. To increase the power to 231 loads, the limit imposed by the fourth, and second worst stage, would require a convoy of 488 camels, which is beyond the capacity of the sixth stage by 111 camels.

The addition of 58 mule carts to the convoy would make good the deficiency, and these could be loaded and despatched before the leading camel of the convoy was ready, as mule carts can be loaded in half the time. The mule carts can move a good deal faster than the camels and would not interfere with the camel convoy.

The power of the line would accordingly be increased to 231 camel loads a day, or by 32 per cent.

102. REDUCING THE LOADS.

This is only applicable when the capacity of the stage is otherwise very low, but is sometimes of advantage under such circumstances,

paradoxical as it may seem to increase the power by reducing the loads carried.

We saw in Section 97, under very unfavourable conditions, the capacity of the sixth stage would fall to 181 camels giving an average power of 90 camel loads for the line.

Now suppose the gross load per camel to be reduced by 10 per cent., with a consequent increase in rate of marching of 5 per cent. This would represent a gain of ·35 of an hour in the seven hours available for marching. We find from the Table of Capacity of Stages, that ·35 of an hour extra would enable us to increase the convoy by 117 camels, making the total convoy 298 camels each capable of carrying 360 lbs.

This would bring the power of the line up to 120 full camel loads of 400 lbs. per day, or an increase of 33 per cent. under the given conditions.

Although camels have been chosen for the illustration, the advantage is more marked with vehicles than with pack transport.

103. EXTRA ESTABLISHMENT FOR LOADING, ETC.

This expedient can be generally applied, either on individual stages or to the line as a whole, unless the latter be a very long one, when the food to be carried for this extra establishment might more than counterbalance the gain in power.

The capacity of the sixth stage, viz. 377 camels, is based on the assumption that it takes two hours to load, and that six hours are available for marching. If, by means of additional establishment at Post VI., the loading can be done in $1\frac{1}{2}$ hours, the time available for marching would be increased to $6\frac{1}{2}$ hours, and the capacity of the stage raised by 215 camels, making it 592 camels. This would increase the power due to this stage to 281 loads a day, so that the power of the line, as a whole, would be now limited to that of the fourth stage, viz., 231 loads a day.

The increase would be 32 per cent.

If a similar expedient were adopted at Post IV., the capacity of the fourth stage could be so increased that the power of the line would be raised to that due to the second stage, or 239, an increase of 37 per cent. By treating Post II. in the same way the power would be that of the third stage, or 245 loads a day, an increase of nearly 40 per cent.

104. CHANGING THE SYSTEM.

If the ground between Posts V. and VI. will admit of an extra post, the original sixth stage may be worked as two short stages.

The capacity of the rearmost short stage, taken as $11\frac{1}{2}$ miles going and returning, would be 477 camels. Allowing for the first term for

convoy and the ratio due to short stages, see Section 90, the 477 camels would allow of 270 loads being delivered daily at the front, and the power of the line would be raised to 231 loads, viz., that of the fourth stage.

105. INCREASING SPARE AND WORKING DAILY.

If the line is already being worked daily, this expedient is not applicable. But when the intention is to allow the men and animals one day's rest in seven, then by adding one-sixth spare the stage can be worked daily, while the same amount of rest is given, one-sixth of the transport resting every day instead of the whole on the seventh day.

On the sixth stage this can be done easily, as there will already be surplus transport at Post VI., the base of the line.

In this way, while the capacity of the stage, and the power of the line, per working day, remains the same as before, the average daily power will be raised from 174 to 204 loads, an increase of 17 per cent.

106. CHANGING THE METHOD OF WORKING.

No gain, but a positive small loss, would result from applying this expedient to the sixth stage of the line given in Section 95, but it is often advantageous when working short stages, or in conjunction with the increased utilization of local supplies, discussed in Section 107.

Assume a short stage of 6 miles (12 miles in all going and returning) on a road with a factor of 1 and a mean width of $13\frac{1}{2}$ ft., and further that the first mile from the rear is broad.

Working "forward" the capacity would be 236 camels.

If, however, the transport for this stage is placed at the post ahead of the short stage and worked "backward" the capacity would be increased 50 per cent.

107. SUPPLY FROM INTERMEDIATE POSTS.

Assume that Post III. on the line given in Section 95, is situated in a fertile district, and supplies Posts IV. and V., the transport for the corresponding stages being located at Posts III. and IV., and working "backwards."

It follows that there is no percentage of increase on the fourth, fifth and sixth stages, and that the ratio remains constant at 1·196. The capacity of the sixth stage is unaltered, but the limit of power due to that stage is raised from 174 to 227 loads daily, an improvement of 30 per cent.

When the scale of food to be forwarded for the transport of communications is large, the gain from fuller utilization of local supplies is very marked, and it may even be economical to locate additional establishments and transport at suitable posts on the line to collect such supplies, when they are not immediately available.

108. THROUGH JOURNEY FOR LOADED VEHICLES.

When the line is being worked with wheeled transport a considerable increase of power is obtained, if the loaded vehicles are passed from stage to stage.

In Section 72 we saw that the time available for marching is increased by one hour by the use of this expedient, and from the Table for the Capacity of Stages the gain of capacity, due to one hour can be obtained by inspection.

109. WHERE ENGINEERING EXPEDIENTS SHOULD BE ADOPTED.

For a given line of communications it is easy, by the method described in Section 95, to determine the stage which limits the power of the line, measured by the daily number of loads delivered at the front. Various transport expedients may then be adopted, see Sections 99 to 108, to increase the power, but ultimately some stage will be found to absolutely limit any further increase.

This is the stage on which engineering attention should at once be concentrated, as any improvement effected will increase the power of the line.

The order in which other stages should be improved depends on their order of inferiority as regards the power of the line, and not on their individual capacity. For instance, if the line is that considered in Section 95 and no transport expedients are adopted, the sixth stage is the worst as regards power, while the second appears the worst as regards the road. But no amount of work on the second stage will increase the power of the line, as long as the sixth stage remains unaltered.

A brief investigation, rendered easy by the use of the Capacity Tables, and in consultation with the supply and transport authorities concerned, will enable the engineers to decide on the order of urgency of the various stages, and to devote their energies, in the first instance, to the improvement of those which would otherwise limit the power of the line.

In addition to this, maintenance gangs should be organized for the various stages, as, unless this is done betimes, the surface is certain to deteriorate from the continuous traffic, and result in loss of power.

110. NATURE OF ENGINEERING EXPEDIENTS.

Leaving out of account the multifarious other duties which fall on the engineers on the line of communications, expedients for improving its power generally group themselves into measures for facilitating the passage of laden and unladen convoys moving in opposite directions, and include the improvement, or provision, of passing places, the construction of return roads for unladen convoys, the provision of additional approaches to storeyards, or to places where convoys can be parked, etc.

The conditions vary somewhat, according to the system adopted by the transport for working the stages, and hence may be most conveniently considered under each of the three systems, full stages, meeting, and short stages.

III. SPECIAL CONSIDERATIONS.

In many of the cases which arrive in practice, a solution by calculation and formulæ would be complicated and cumbrous. The required results can generally be easily obtained by means of the Tables for the Capacity of Stages.

There are several points which must be noted, as preliminary to any investigation.

(1). The surface of a newly-constructed road, or portion of road, is generally inferior, so that the road factor would be about ·1 less for pack transport, or ·2 less for wheeled transport, than on the original road. Against this must be put the fact that the factor may be increased by ·2 for unladen transport. The resulting road factor for the new road must be determined for the unladen transport.

(2). The marching time for the unladen convoy is generally greater than when laden, as it can move off or settle down in half an hour. The difference between these, and the time occupied in loading, unloading, etc., see Section 71, may be added in whole, or in part, to the marching hours of the laden convoy, to obtain that available for the empty one. This will be found to have an important bearing on the position of passing places.

The "opened-out length of the convoy" enters into such calculations.

The length of convoy when formed up can be got by dividing the number of pack animals, or vehicles, by the number per mile as given in Table IX., p. 54. The "opened-out length" can be obtained, with sufficient accuracy for practical purposes, by multiplying the coefficient given below, by the length when formed up.

	F=·1	F=·7	F=·4
Animal Transport.			
Medium road	1·3	1·5	1·7
Narrow road	1·5	1·75	2·0
Mechanical Transport.			
Medium road	1·8	2·1	2·4
Narrow road	2·2	2·7	3·2

112. CENTRAL PASSING PLACE ON NARROW ROAD (FULL STAGES).

On a medium, or narrow, road when working full stages a convoy moves, laden one day, and returns empty the next, so the average delivery of the stage is half its daily capacity.

If we widen the road midway, for a sufficient length to admit of laden and unladen convoys passing each other on the march, we practically double the delivery, as the stage can be worked daily to its full capacity.

Assume a stage 10 miles long, with a road factor of ·9, and a mean width of 13½ ft., worked by camels. From the Capacity Table we find the convoy cannot exceed 343 camels, so the average delivery is 171·5 camel loads daily. If a passing place is provided, we can forward 343 camel loads daily, alloting double the number of camels to the stage.

As 350 camels occupy 1 mile of road the length of road to be widened to secure this result is, say, 1×1·4 or 1·4 miles, roughly ¾ mile on each side of the centre of the stage.

113. ECCENTRIC PASSING PLACE ON NARROW ROAD (FULL STAGES).

It may often be impracticable to widen the road at the middle of the stage, owing to cliffs, retaining walls, heavy cuttings, etc., either because of the lengthy work involved, or to the resulting interference with traffic. While some adjacent section may be widened with comparative ease.

In such a case, we must calculate for the laden and unladen convoys separately, using for each the approximate time and road factor. The smaller of the two convoys represents the capacity of the stage.

For example, assume a stage of 10 miles, with a factor of ·9 and a width of 13½ ft., worked by camels, and that the centre of the passing place is 2½ miles from the far end of the stage.

The laden convoy is 343 camels, found by inspection from Table XI., p. 72, and is unaffected by the position of the passing place, being given precedence.

The rate of march being 2·25 on a standard road where F=1, see Table IX., the rate when F=·9 is 2·25×·9, or, say 2 miles an hour for the head of the laden convoy. It thus takes 3·75 hours to reach the centre of the passing place, leaving a balance of 2·25 hours out of the six.

The empty convoy gains 1·5 hours as it has no unlading, etc., and so has 2·25+1·5, or 3·75 hours in which to march 7½ miles,* its road factor being unity.

Using the Capacity Table :—

Convoy to march 10 miles in 6 hours	.. ..	580
For 2½ miles less, add 2½×164	.. ..	+410
Convoy to march 7½ miles in 6 hours	.. ..	990
For 2·25 hours less, deduct 2¼×357	.. ..	−803
Convoy to march 7½ miles in 3·75 hours	..	187

The capacity is the lesser of the two convoys or 187 camels a day.

The length of road to be widened will be $\frac{187}{350}\times 1\cdot4$, or ·75 of a mile.

* If the unladen convoy has to march more than half the length of the stage before reaching the centre of the passing place, calculate for the stage reversed.

114. LIMITS OF PASSING PLACES TO SECURE FULL CAPACITY ON NARROW ROAD (FULL STAGES).

If F be the factor for the laden, and F′ that for the empty convoy, deduct from the length of stage, the distance the empty convoy can march, in the time saved owing to there being no necessity for loading up.

Then, the centre of the passing place must not be farther from the end of the stage than $\frac{F}{F+F'}\times$ the above remainder.

Using the previous example, F=·9, F′=1, and time saved by empty convoy=$2-\frac{1}{2}=1\frac{1}{2}$ hours.

Rate of head of empty convoy=$2{\cdot}25F'=2{\cdot}25$.

Distance marched in 1·5 hours=3·37 and $10-3{\cdot}37=6{\cdot}63$ miles.

The centre of the passing place must not be farther from the end of the stage than $\frac{{\cdot}9}{1{\cdot}9}\times 6{\cdot}63$, or 3·1 miles.

The passing place might be situated at any point within, roughly 2 miles of the centre of the stage, while still retaining the full capacity of 343 camels per day.

The length of road to be widened would be 1·4 miles.

115. LIMITS OF PASSING PLACES TO SECURE SOME INCREASE OF CAPACITY ON NARROW ROADS (FULL STAGES).

The method of arriving at this will be shown by means of the same sample stage.

There will be no increase of capacity, when the length of daily convoy falls to $\frac{343}{2}$, or 171 camels.

Find the length of empty convoy as in Section 112, when the passing point is 4 miles from the end, and again, when it is 3 miles from the end of the stage, using the Capacity Tables.

When 4 miles from the end	700	camels.
When 3 miles from the end	358	,,
For difference of 1 mile	342	,,
When 3 miles from end	358	,,
Minimum convoy permissible	171	,,
Difference	187	,,

But 187 camels represent $\frac{187}{342}$ or ·54 miles.

So the passing point must not be nearer the end of the stage than

3 = ·54, or 2·46 miles, otherwise there will be no gain of capacity from the provision of a passing place.

116. Diversion Roads in Lieu of Passing Places (Full Stages).

It may frequently be found easier to make a diversion road for the unladen transport, than to widen the existing narrow road. This may be due to the heavy work involved in widening, or when interference with traffic during such operations would be unavoidable.

As a diversion for unladen convoys need not be so carefully graded as the original road, it is often possible to construct it without much labour, and, when well designed, it is always more satisfactory than a passing place, since, on the latter, there is the risk of interference in the smooth passage of the convoys due to restive animals, a risk which is entirely obviated by the use of a diversion.

The two essentials in planning a diversion are, first, that the rear of the unladen convoy must be clear of the main road before the head of the laden convoy arrives, and second, that the rear of the latter must be past the point where the diversion rejoins the main road, before the head of the empty convoy moves on to it again.

Generally speaking, the conditions will be fulfilled, if the length of the diversion is twice the opened-out length of the convoy, less the distance between the points, where it leaves and rejoins the main road, measured along the latter.

Problems concerning diversions can be solved on much the same lines as for passing places. The point of departure for the unladen convoy is that, where it leaves the main road. The distance to be marched is from this point to the end of the stage, measuring along the diversion. The time available is that saved at the start, there being no loading up, plus the difference between the marching hours allowed for the laden convoy, less the time taken by the head of the latter to reach a point, its opened-out length short of that where the empty convoy leaves the main road.

Where there is a decrease in capacity, it may be necessary to repeat the calculation for the diminished size of convoy, and obtain the correct result by interpolation.

117. Capacity of Narrow Road with Diversion (Full Stages).

The method of arriving at the above may best be illustrated by an example.

Assume a stage of 9 miles, where F = ·9, and width of road is $13\frac{1}{2}$ ft., worked by camels. A diversion is made for the unladen return convoy, leaving the main road 4 miles from the far end of the stage, and rejoining it after a mile. The length of this diversion is 3 miles, its factor is ·9 and its width $13\frac{1}{2}$ ft.

Using the Table for Capacity of Stages we find :—
For laden convoy :—

Convoy to march 10 miles, in 6 hours	343
For 1 mile less, add 1×161	+161
Convoy to march 9 miles in 6 hours	504

The opened-out length of convoy is $\frac{504}{350} \times 1{\cdot}4 = 2$ miles.
For the unladen convoy :—
First make sure the diversion is long enough to prevent delay. The minimum length is twice the opened-out length of laden convoy, less the distance between the points where the diversion leaves, and rejoins, the main road. This is $2 \times 2 - 1$, or 3 miles. The diversion is just long enough.*

Length to be marched $3+4$, or 7 miles.

Time available, $1{\cdot}5+\left(6-\frac{5-2}{2}\right)$, or 6 hours.

Convoy to march 10 miles in 6 hours	343
For 3 miles less, add 3×161	+483
Convoy to march 7 miles in 6 hours	826

The capacity of the stage is the smaller of the two convoys or 504 camels daily.

118. PERMISSIBLE VARIATION IN LENGTH OF DIVERSION.

It is desirable to know the permissible variation in the length of a diversion, in order that the fullest advantage of the ground may be taken, to avoid heavy work in construction, without lowering the capacity of the stage.

The minimum length would theoretically be such as would just suffice to hold the convoy in column of route, but in practice it should be at least 10 per cent. longer. For the example in Section 117 it would be $\frac{504}{350}$ plus 10 per cent., or 1·58, say, 1·6 miles.

The maximum length may be arrived at as follows :—

Convoy to march 7 miles in 6 hours	826
Actual convoy for full capacity	504
Difference	322

An unladen convoy of 504 camels could thus march $\frac{322}{161}$ miles more than 7 miles in the time available, 161 being the tabular correction for a difference of 1 mile in the length of march.

* Had the diversion been $2\frac{1}{2}$ miles long, the distance to be marched must be taken $3-2\frac{1}{2}+2\frac{1}{2}+4$, or 7 miles, instead of $2\frac{1}{2}+4$, or $6\frac{1}{2}$ miles.

The convoy could march 9 miles, 4 miles of which are after it rejoins the main road.

The maximum length of diversion retaining the full capacity of the stage is accordingly 9 – 4, or 5 miles.

119. GRADIENT PERMISSIBLE ON A DIVERSION.

Again, using the example in Section 117, the method is as follows :—

The length of convoy for full capacity is 504 camels.

We first find what road factor would allow of 504 camels marching 7 miles in 6 hours.

	If F = ·8.	If F = ·7.
Convoy to march 10 miles in 6 hours ..	126	– 94
For 3 miles less, add 3 × correction ..	474	+465
Convoy to march 7 miles in 6 hours ..	600	371

When F = ·8, convoy 600
When F = ·7, convoy 371

Difference ·1 229

The actual convoy is 96 less than 600, so the corresponding value of F would be $\frac{96}{229}$ less than ·8.

This makes F = ·76, for the 3 miles of diversion and 4 miles of main road, taken as a whole.

Proceeding as in the last paragraph of Section 73,

When F = ·76, reciprocal = 1·316 ; march 7 miles ; 1·316 × 7 = 9·212
When F = ·9, reciprocal = 1·111 ; march 4 miles ; 1·111 × 4 = 4·444

Difference .. .. 4·768

The length of diversion being 3 miles, the reciprocal of its permissible value of F is 4·768 ÷ 3, or 1·59, so F = ·63. Allowing that the road factor has been increased by ·1 for unladen transport, the factor for gradient and surface would be ·53.

Assuming the surface to be indifferent, we see from the table in Section 73, that ·53 corresponds to a gradient of about 1 in 9. If the surface were bad, the corresponding gradient would be about 1 in 12.

These gradients could be used on the diversion without affecting the capacity of the stage.

120. PARKING UNLADEN CONVOYS USING NARROW ROAD (FULL STAGES).

This expedient can often be adopted when suitable ground exists near the road, although it may be impracticable to make a diversion, or to widen the existing road. The parking ground may be some

distance from the actual road, without affecting the capacity, but care must be taken that the space does not become congested, or the entrance and exit blocked.

The point at which the unladen convoy leaves the main road is the datum of the calculation.*

The minimum length of march for the unladen convoy, is the remainder of the stage after it rejoins the main road, plus twice the opened-out length of the convoy, minus the distance, measured along the main road, between the points where the convoy leaves and rejoins it. The total distance the unladen convoy has to march from the point where it left the main road must be substituted for the above minimum, if greater.

The time available is that gained at the start, owing to there being no unloading, plus the difference of time between the marching hours for the laden convoy, and that taken by its head to reach a point its opened-out length short of where the unladen convoy quitted the road.

121. CAPACITY WHEN PARKING.

Assume a stage 9 miles long, with a road factor of ·9 and a width of $13\frac{1}{2}$ ft., worked by camels. Suitable parking ground is found $\frac{1}{2}$ mile off the road, and is connected with the main road by two short branches $\frac{1}{2}$ mile apart. That by which the unladen convoy quits the main road is 4 miles from its own end of the stage.

Proceed as in Section 117.

For laden convoy :—

Convoy to march 9 miles in 6 hours	504

Opened-out length of convoy 2 miles.

For the unladen convoy :—

The total distance marched by this convoy off the main road is, say, $\frac{3}{4}$ mile, so we must use the maximum of $(2 \times 2) - \cdot 5$, or 3·5 miles.

Length of march 4·5+3·5, or 8 miles.

Time available, $1 \cdot 5 + \left(6 - \frac{5-2}{2}\right)$ or 6 hours.

If F be taken as ·9

Convoy to march 10 miles in 6 hours	343
For 2 miles less, add $2 \times 1 \cdot 61$	322
Convoy to march 8 miles in 6 hours	665

The capacity of the stage is 504 camels daily, instead of an average of 252 daily without this expedient.

* This is when the unloaded convoy leaves the main road before it reaches the centre of the stage. If it leaves after passing the centre, calculate as if the stage were reversed.

122. PERMISSIBLE DISTANCE OF PARKING PLACE FROM ROAD.

Making use of the example given in the last section the procedure is as follows :—

Unladen convoy to march 8 miles in 6 hours ..	665
Actual convoy	504
Difference	161

A convoy of 504 unladen camels could march $8+\frac{6}{16}$ or 9 miles in 6 hours.

The distance to be marched after it rejoins the main road is $4\frac{1}{2}$ miles, which leaves a balance of $4\frac{1}{2}$ miles.

If we assume that $\frac{1}{2}$ mile is required on the actual parking ground, the latter might be $\frac{4\frac{1}{2}-\frac{1}{2}}{2}$, or 2 miles from the road, without decreasing the capacity of the stage.

It must be noted, however, that with approaches of this length the parking ground would not be required, the case having merged into that of a diversion, once the sum of these approaches exceeded one-tenth the length of the convoy.

123. RETURN ROAD FOR UNLADEN CONVOYS.

When a narrow road throughout the stage is duplicated, a return road for empty convoys having been constructed, the increase of capacity* is much the same as when passing places, diversions, or parking is resorted to. As, however, the unladen convoy is no longer compelled to adapt its marching to that of the laden convoy, its work is reduced, its rest increased, and to this extent the efficiency of the stage enhanced.

Assume a stage of 9 miles, with road factor ·9 and a width of $13\frac{1}{2}$, worked by camels, and a return road of the same length in which the factor is the same after allowing for the increase due to unladen transport.

A convoy of 504 camels can complete the march in 6 hours. As the empty convoy has no loading or unloading, and marches quite independently on the return road, it has 3 hours' additional rest, which can be arranged for at either end of the stage, and devoted to grazing, etc.

We saw with the diversion in Section 117 that the capacity was the same, but the gain of time relative to the laden convoy was only $1\frac{1}{2}$ hours, and that was restricted to the early morning before it started.

* The capacity is actually slightly increased, but such increase would not exceed 10 per cent. of the capacity obtained from the Table for Full Stages.

124. ENGINEERING EXPEDIENTS UNDER MEETING SYSTEM.

These are not productive of such substantial increase of capacity as the system itself limits their application to a much larger extent.

The meeting place may be varied to a small degree without loss of capacity on both broad and narrow roads in the case of ordinary working. Similarly the transferring ground, where one convoy hands over its loads to the other, may be located a little off the road. And lastly the approaches to this ground may be improved. The latter expedient when applied to narrow roads is the only one of the three which causes an appreciably increased capacity of the stage.

125. LIMIT OF VARIATION IN POSITION OF MEETING PLACE.

In Section 70, dealing with the working hours the operations of loading and of unloading and stacking are both included in the period of 12 hours allowed, but it is obvious that both these operations do not fall to the same convoy once the loads are transferred. As an unladen convoy can move off, or settle down, in half an hour, the difference between this and the time required for loading (unloading and stacking take approximately the same time) is available, if necessary. But it must be noted the number of working hours for the stage, as a whole, is increased by this amount. This does not affect the individual convoy, but does affect the establishment at the posts, and so has been left out of account in constructing the table for the meeting system.

If the Transport Authorities decide that this gain of time is admissible, but prefer to use it in increasing the capacity of the stage, then the meeting place must be in the centre of the stage, and no alteration is possible without loss of capacity. When, however, it is impracticable to arrange for the transfer of loads at this point, the meeting place may be shifted within certain limits, without decreasing the capacity obtainable in 12 working hours.

Assume a stage of 9 miles, worked by bullock carts on the meeting system, the road having a factor of ·9 and a width of 12 ft.

Convoy to march 10 miles in 7 hours	207
For 1 mile less add 1×78	+78
Convoy to march 9 miles in 7 hours	285

The capacity of the stage for 12 working hours is 285 carts.

The time taken in loading is 1 hour, while an unladen convoy could get off in ½ hour; the possible extra time available is thus ½ hour.

(*a*). If this time be used to increase the capacity, working for $12\frac{1}{2}$ hours—

Convoy to march 9 miles in 7 hours	285
For $\frac{1}{2}$ hour more, add $\frac{1}{2} \times 135$	+67
Convoy to march 9 miles in $7\frac{1}{2}$ hours	352

(*b*). If the time be used to vary the position of the meeting place.

The increase of convoy for an extra $\frac{1}{2}$ hour is 67, and the correction for 1 mile is 78, so the meeting place might be varied on either side of the centre of the stage by half of $\frac{67}{78}$ of a mile.

The permissible variation either way is nearly $\frac{9}{20}$ of a mile, while retaining a capacity of 285 carts daily, but working for $12\frac{1}{2}$ hours.

(*c*). When, even with this expedient, a suitable transferring place cannot be found or constructed within these limits, the nearest suitable should be chosen, and the consequent loss of capacity faced.

The length of stage is then taken as twice the longer portion.

Assume that a suitable place for the transfer of loads is 1 mile from the centre of the actual stage, distant 5 and 4 miles respectively from the two ends. The length of stage for purposes of calculation must be taken as 10 miles. The capacity is that due to a stage of 10 miles in $7\frac{1}{2}$ marching hours.

Convoy to march 10 miles in 7 hours	207
For $\frac{1}{2}$ hour more, add $\frac{1}{2} \times 135$	+67
Convoy to march 10 miles in $7\frac{1}{2}$ hours	274

The effect is that the capacity of the stage falls to 274 carts a day, which is 11 below that for normal working 12 hours a day, or 78 below the maximum working $12\frac{1}{2}$ hours a day.

126. DISTANCE OF TRANSFERRING GROUND FROM ROAD.

The maximum capacity will be greater the nearer the transferring ground is to the road, but it may be located a little way from the road without affecting the ordinary capacity for 12 working hours.

The procedure is practically identical with that followed in last section, and the transferring ground, in the example there given, might be removed from the road a distance equal to that by which the meeting place can be varied from the centre of the stage, viz. ·45 of a mile, with a central meeting place.

If the transferring ground were $\frac{1}{2}$ mile from the road, and reached by an approach perpendicular to the main road, and $\frac{3}{4}$ mile distant

from the centre of the stage, the capacity must be calculated as for a stage of 2 ($4\frac{1}{2}+\frac{3}{4}+\frac{1}{2}$), or $11\frac{1}{2}$ miles.

Convoy to march 10 miles in 7 hours	..	..	207
For $1\frac{1}{2}$ miles more, deduct $1\frac{1}{2}\times 78$	..	..	117
Convoy to march $11\frac{1}{2}$ miles in 7 hours	..	..	90

If the transport authorities agree to $\frac{1}{2}$ hour addition to the working hours, to the above add the correction for $\frac{1}{2}$ hour, or 67 carts, making the capacity for $12\frac{1}{2}$ hours come to 184 carts.

It will be observed that the above is calculated on the assumption that the approach road is perpendicular to the main road. By constructing two approach roads, each on the hypotenuse of a triangle, the distance to be marched is reduced, and the capacity increased.

For instance, if the approach roads were on the hypotenuse of a right-angle triangle, the length of stage used for calculation would be 10·9 miles, and the capacity would be increased by $\cdot 6\times 78$, or 46 carts. This is indeed the only way in which the engineers can improve the capacity of broad roads under the circumstances considered.

127. Widening or Duplicating the Approaches to the Transferring Ground, for Narrow Roads.

The adoption of this expedient on narrow roads greatly increases the capacity of the stage when a transferring ground is used.

The calculation is now made with the Table for Full Stages, correcting for the difference in marching hours between the two systems, and the length of stage being assumed to be, as before, double the distance marched by that convoy which has furthest to move when laden.

The length of road, including approaches, to be widened or duplicated is theoretically half the opened-out length of the convoy, less half that occupied by the number of vehicles, or pack animals, which can march on to the ground during the time required to transfer loads. But in practice the deduction may be neglected, unless the heavy nature of the work involved renders it desirable to retain it.

Assume as before a stage of 9 miles worked by bullock carts on the meeting system, the transferring ground being at the centre of the stage. The road is assumed to have a factor of ·9 and a width of 12 ft.

The capacity of the unaltered road is 285 carts.

After the expedient is adopted we calculate by the Table for Full

Stages, deducting 1 hour for the difference in the marching hours between the two systems (see table).

Convoy to march 10 miles in 8 hours	500
For 1 mile less, add 1×113	+113
Convoy to march 9 miles in 8 hours	613
For one hour less, deduct 1×195	−195
Convoy to march 9 miles in 7 hours	418

The capacity for the stage for 12 working hours has been increased from 285 to 418 carts per day.

The length of road to be widened, or duplicated, must be calculated for the increased convoy of 418 carts.

The opened-out length of column for 418 carts is $\frac{418}{250}\times 1{\cdot}4$ or, say, 2·4 miles.

The length of road, to be widened, or duplicated, need not exceed $\frac{2{\cdot}4}{2}$ or 1·2 miles.

If the work involved be heavy, and it is advisable to allow for the carts accommodated on the transferring ground itself, the approximate deduction may be arrived at as follows :—If the carts marched at the same rate as the leading one, the rate would be 2×F, two being the rate on a good road (Table IX.) and F the factor for the road they are using. The time taken in the transfer is 1 hour, see Section 71, so in this time if all moved at the rate of the head of the column, which they do not, 1×2×·9, or 1·8 miles of carts would arrive. A more correct result is obtained by dividing 1·8 by the coefficient for opened-out length of column, which is 1·4. Thus $\frac{1{\cdot}8}{1{\cdot}4}$, or 1·3 miles of carts can arrive in 1 hour.

The minimum length of road to be widened or duplicated on each side of the transferring ground, would accordingly be $1{\cdot}2-\frac{1{\cdot}3}{2}$, or, say ·6 of a mile.

Where duplicate roads are constructed, those to be used by the laden convoys, approaching and leaving the transferring grounds, should be the shortest and best, while the longer or inferior ones should be for the returning empty convoys. Before deciding on the location of the latter, the transport authorities should be consulted as to the organization and arrangement of the convoys on the transferring ground itself, as the movements of the laden convoys must on no account be impeded by those returning unladen.

128. ENGINEERING EXPEDIENTS FOR SHORT STAGES.

Excluding the construction of roads to facilitate movements in, or round, the storeyards at the posts, which fall to the lot of the

Engineers in any case, the only practical expedient for increasing the capacity of the stage is by widening, or duplicating, the road just short of the post to which the convoy proceeds laden. The effect on broad roads is very slight, but on narrow roads a considerable gain in capacity may be secured.

In the latter case calculate the capacity by the use of the Table for Full Stages, instead of that for Short Stages, the length of stage being reckoned as the total distance the convoy has to march going and coming, and the time available being assumed to be increased by $\frac{1}{2}$ hour.

129. WIDENING OR DUPLICATING A NARROW ROAD FOR SHORT STAGES.

The portion of road to be widened or duplicated is just short of the post to which the convoy proceeds laden, and the maximum length which need be so treated is half the opened-out length of the convoy. The minimum length to be widened or duplicated is the above distance less the length of column which can move into the storeyard during the time it takes to unload.

Assume a short stage of $4\frac{1}{2}$ miles worked by bullock carts, and that the road has a factor of ·9 and a width of 12 ft.

Convoy to march 10 miles in 8 hours	394
For 1 mile less add 1×80	+80
Convoy to march 9 miles in 8 hours	474

When the road has been widened or duplicated we use the Table for Full Stages, and assume the time available for marching to be $8\frac{1}{2}$ hours.

Convoy to march 10 miles in 8 hours	500
For 1 mile less, add 1×113	+113
Convoy to march 9 miles in 8 hours	613
For $\frac{1}{2}$ hour more, add $\frac{1}{2}$×195	+97
Convoy to march 9 miles in $8\frac{1}{2}$ hours	710

The capacity has been increased from 474 to 710 carts, an increase of about 50 per cent.

The maximum length of road which need be widened is $\frac{1}{2}\times\frac{710}{550}\times 1{\cdot}4$, or 2 miles.

The minimum length of road to be widened or duplicated is obtained as follows :—

As the time taken in unloading is $\frac{1}{2}$ hour, see Section 70, the length of column which could march into the yard in this time $\frac{1}{2}\times 2\times{\cdot}9$, or ·9 of a mile, divided by the cofficient for opened-out length of column, viz., 1·4.

The minimum length of widened or duplicated road is accordingly $2 - \frac{1}{2}\frac{\cdot 9}{1\cdot 4}$, or, say, 1·7 miles.

130. LIMITS IN USE OF DUPLICATE ROADS FOR SHORT STAGES.

In Section 129 we found that the capacity of a short stage might be increased by some 50 per cent., by widening or duplicating a short length of narrow road.

In the case of duplicate roads, the full percentage of gain can only be obtained provided the duplicate road for the returning empty convoy does not increase the total distance to be marched, and has a road factor equal to that of the original road.

In practice neither of these conditions may be fulfilled, and the capacity will fall off, until ultimately the gain from the engineering work will vanish entirely.

To be able to establish this limit is therefore of value to prevent the engineers wasting labour, which might be more usefully employed elsewhere.

We saw in the example given in Section 129 that the capacity could be increased from 474 to 710, a difference of 236 carts, provided that 2 miles of road were duplicated, and that both had ·9 as a factor.

As the correction of 1 mile is 113, the duplicate road might be $\frac{236}{113}$, or nearly 2 miles longer before the capacity fell to that of a narrow road provided the factor remained unaltered.

Conversely if the duplicate road did not increase the total distance to be marched, the road factor might be reduced to that which will suffice to allow of a capacity of 474 carts daily. This factor may be calculated as follows:—

	F=·8.	F=·7.
Convoy to march 10 miles in 8 hours ..	310	130
For 1 mile less, 1 × correction ..	+110	+107
Convoy to march 9 miles in 8 hours ..	420	237
For ½ hour more, ½ × correction ..	+85	+72
Convoy to march 9 miles in 8½ hours ..	505	309

When F=·8, convoy=505
When F=·7, convoy=309

Difference ·1 196

Convoy for F=·8	505
Actual convoy	474
Difference	31

So the value of F for the stage may be reduced to $\cdot 8 - \frac{1}{15}$, or say, $\cdot 79$, before the capacity falls to that of the unaltered road.

The factor of the stage, as a whole, being $\cdot 79$ while that for the 7 miles marched on the original road is $\cdot 9$, the factor for the new duplicate portion of 2 miles can be found.

Reciprocal of $\cdot 79$ is $1 \cdot 26$; $1 \cdot 26 \times 9$	$11 \cdot 34$
Reciprocal of $\cdot 9$ is $1 \cdot 11$; $1 \cdot 11 \times 7$	$7 \cdot 77$
Difference	$3 \cdot 57$

The reciprocal of the road factor for the duplicate road is $3 \cdot 57 \div 2$, or $1 \cdot 88$, so the road factor permissible is $\cdot 54$.

131. WHETHER TO CONSTRUCT A DUPLICATE ROAD, WHEN BOTH LENGTH AND FACTOR VARY.

This will best be illustrated by an example :—

The short stage, the improvement of which is under consideration is $4\frac{1}{2}$ miles long, and is worked by bullock carts. The road has a factor of $\cdot 9$ and a width of 12 ft. The duplicate road, on the only possible alignment, has a length of $2\frac{1}{4}$ miles, and rejoins the main road 2 miles on. It is not considered advisable to allow this new portion a higher factor than $\cdot 75$, considering gradient and surface. Will the construction of this duplicate road increase the capacity of the stage ?

We must first find the mean value of the road factor for the stage as a whole.

The distance to be marched would be $4\frac{1}{2} + 2\frac{1}{4} + (4\frac{1}{2} - 2)$, or $9\frac{1}{4}$ miles, of which 7 are on the original road.

The reciprocal of $\cdot 9$ is $1 \cdot 11$; $1 \cdot 11 \times 7$	$= 7 \cdot 77$
The reciprocal of $\cdot 75$ is $1 \cdot 33$; $1 \cdot 33 \times 2\frac{1}{4}$	$= 3 \cdot 00$
Sum	$10 \cdot 77$

The reciprocal of F is $\frac{10 \cdot 77}{9 \cdot 25}$, or $1 \cdot 17$; so F $= \cdot 86$.

	F $= \cdot 9$.	F $= \cdot 8$.
Convoy to march 10 miles in 8 hours ..	500	310
For $\frac{3}{4}$ mile less, add $\frac{3}{4} \times$ correction ..	$+85$	$+82$
Convoy to march $9\frac{1}{4}$ miles in 8 hours ..	585	392
For $\frac{1}{2}$ hour more, add $\frac{1}{2} \times$ correction ..	$+97$	$+85$
Convoy to march $9\frac{1}{4}$ miles in $8\frac{1}{2}$ hours	682	477

When F $= \cdot 9$, convoy $= 682$
When F $= \cdot 8$, convoy $= 477$

Difference $\cdot 1$ 205

The convoy when F = ·86 is accordingly $477+\frac{6}{10}205$, or 600.

As the proposed duplicate road would increase the capacity from 474 to 600 carts a day, its construction is advisable.

132. Return Road for Short Stages.

In some instances when the diversion would be long, the latter may be converted, with advantage, into a return road. This gives a further slight increase of capacity amounting to something between 5 and 10 per cent. The method of calculation is similar to that described in the last section.

133. Basis of Method Described.

The investigation of the factors governing the rates of marching under varying conditions was first undertaken after the operations in Thibet in 1903–04, where the long line of communications included roads of every description, from broad, metalled, and nearly level roads, to mere mule tracks, 6 ft. wide or less, and with gradients approaching 1 in 3 in the worst sections, and surfaces hardly susceptible of classification. The conditions under which this line was worked also varied enormously, being at certain times for certain localities favourable, and in other instances most unfavourable from a combination of adverse circumstances, such as high altitudes, temperatures far below zero, blizzards and snowstorms, while it took time for both men and animals to become accustomed to the novel conditions.

A great variety of transport was employed, including bullock carts, mule carts and pony carts, and among pack transport, camels, mules, ponies, yaks, pack bullocks, donkeys, and coolies.

The nature of the expedition, mainly dependent on India for supplies which had to be carried over lofty passes under the conditions already indicated, necessitated the most careful and continuous watch being maintained on the work of the various stages, as at times an error of only 7 per cent. on the line, would have meant that nothing reached the force in front.

Careful notes were kept of the number of loads passed over the various stages under varying conditions, and there was thus accumulated a mass of data which formed the basis of subsequent investigation. Additional data were obtained from other campaigns from personal observation, from information kindly supplied by other officers, and from military history in cases where sufficient detail was given to admit of analysis.

It had already been established in the past that the rate of the rear of a column falls off as the length is increased, and it is obvious that the rate of the head of a column must be affected by the gradients

and surface of the road, and the conditions under which the march is carried out. Calculations based on the above considerations, however, failed to give reliable results in a large number of cases.

It was found by careful comparison of cases that when everything except the width of road was identical, the rate of marching of the rear of a column decreased to an appreciable extent with the width of road, and empirical coefficients had to be determined to allow for this disturbing feature.

Formulæ embracing this correction gave better results, but it was apparent from the analysis of widely differing cases, that certain other causes of variation must be determined and allowed for, if the formulæ were to be of general application.

Some of these were very difficult to estimate as they concerned loss of strength due to the strain on the muscles of the animals and on their circulatory and respiratory organs.

A healthy and properly nourished animal can produce daily a certain amount of energy, a considerable portion of which is consumed on the phenomena of life, the balance only being available for work. Any excess over this must be at the expense of the organism itself.

Thus in estimating the work done during a march we must consider that required to overcome the force of gravity due to the gradient, which is susceptible of calculation, that due to the resistance of the surface, which has been established by experiment, and must allow for the additional expenditure of energy on increased strain on the muscles and on the respiratory and circulatory systems. This additional strain is equivalent to work which cannot be exactly determined, both because of its inherent obscurity, and also because the animal will instinctively adapt its pace to lessen the discomfort due to the above causes. Thus reduced to its simplest terms, and neglecting other external conditions, the work in marching depends on gradient, surface, and an unknown variable, representing the additional energy which is expended in the organism.

The above remarks will make it sufficiently clear that in the case of animals the work done in marching cannot be determined by purely mathematical analysis, although it may be obtained approximately.

The factors for gradient with a correction for surface, though based on mathematical principles, have been fixed empirically to give sufficiently close results in actual practice, when estimating the rate of march. Their apparent departures from the true mathematical relation counterbalance each other to some extent, and the algebraical sum represents very nearly the reciprocal of the work after allowance has been made for the variable component due to increased strain.

134. A Close Approximation Aimed At.

Coefficients for the various conditions affecting the march having been empirically established by the analysis of a large number of cases, an attempt was made to obtain formulæ of general application to all cases. But these proved too complicated to have any practical value in the field.

Approximations were then resorted to in which the number of factors to be taken into account were reduced, and the coefficient varied accordingly to secure simplicity. But even so the resulting formulæ, restricted to deal with marches within the limits obtainable in practice, were too cumbrous, and involved the solution of quadratic and even cubic equations

On the advice of a senior officer of great experience, a distinguished commander in the field, the attempt to produce formulæ of practical utility was abandoned in favour of tables which could be used by any officer of average ability. The construction of these tables involved much laborious calculation, both originally and in the subsequent process of checking. They do not pretend to absolute accuracy, but are in the nature of approximation, which should not be in error to the extent of 10 per cent., and should generally give even closer results.

135. Conclusion.

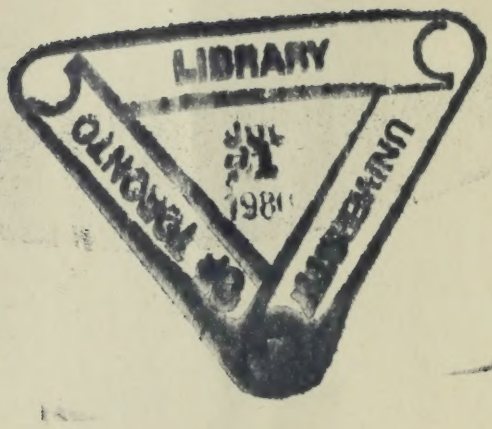
The advantage of being able to estimate, even approximately, the amount of transport to be allotted to each stage of a line of communication must be apparent to every officer of practical experience.

It is true that the power which can be usefully employed can be gradually determined by the actual working of the stages irrespective of any such estimate, but the process is both lengthy and wasteful. To gauge the actual work of a stage, nearly a week will elapse, as the minor daily fluctuations have to be eliminated. To increase the transport on the stage will take a day or two, sometimes much more. A further week will elapse before it can be judged whether or not the additional transport is doing its full share of work. If the correct amount necessary to develop the full capacity of the stage has not been accidentally arrived at a further alteration must be made. It is impossible to treat all the stages at once as they to some extent react on each other. So, on a long line of communications, weeks or even months must elapse before all the stages have been adjusted by the system of trial and error; meanwhile much of the transport power has been wasted, and before the adjustments have been completed, a change in the season may nullify the improvements already attained. Similarly the work of the engineers on the

road may also be thrown away to a large extent, as labour may have been expended on stages which have no effect on the power of the line, though the fact has not been at once apparent.

Any method of determining approximately the capacity of the various stages makes for economy of transport and of labour. Adjustments may still have to be made, but they will be smaller in degree, and the efficiency of the line, as a whole, will be increased from the beginning. The effect of future seasonal changes in the conditions under which the stages are worked may be, to some extent, allowed for, while the measures required to improve the line, whether from the transport or engineering point of view, can be devoted, in the first instance, to those stages which limit the output of the line.

In the preceding pages an attempt is made, however inadequate, to evolve and elucidate such a method, and it is hoped that these Notes, crude as they are, may be of assistance to brother officers whose work is connected with the lines of communication.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